Proposal of Improvement for the Dinghy 470

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Contents

1. Introduction 3

2. The 470 4

3. The 470 Nowadays 5

Dynamic: 5

Global: 6

Physical: 7

Challenging: 8

Exhilarating: 9

4. The 470 at the Olympics Games 10

5. The 470 keys to success 12

6. The Improvement Targets 13

7. The Sails 15

How a sail should be? 15

The Sailcloth Characteristics 15

The Sail Geometry 18

Conclusion of the Sails theory. 27

V1 Sails Rules 28

V3 Sails Rules 33

Computational Fluid Dynamics Test 38

Dominance Ratios 44

8. The Mast 46

V3 Rig Rules 51

Rig conclusions 58

9. The Hull 59

Deck Shapes 60

The structure and the production process 63

The materials: 67

Hull Conclusions 70
10. Conclusions 71
11. Project Evaluation 75
Appendix 1 76
Current 470 Rules 76
V1 Sails Rules 110
V3 Sails Rules 115
V3 Rig Rules 119
Appendix 2 127
Current 470 Building Plan 127
New 470 Reinforcements Specification Plan 128
Appendix 3 CFD Chart 129
Appendix 4 Maxsurf Pictures 130
Bibliography 131

1. Introduction

I'm Aleix Sellés. I was born in Barcelona on 22nd of September of 1987. Since I was young I enjoyed doing sports and I always had contact with sea. As you will see, this final project is not related just with my degree, it's closely related with my sport career and my concern and interest for the subject.

When I was 12, I began sailing in summer holidays doing courses in CMV[1]. After some courses at age of 15 I moved to l'Equipe[2] class and I was introduced to regattas world, that attracted my attention and I began to sail almost all the weekends. In those days I defined myself as a crew.

At 16, I was too old for the l'Equipe and I started sailing in 420[3] where I sailed for 6 years. In this class I achieved some good results like Spanish and Catalan champion or podium place in international regattas. From this age I've sailed in some cruise too, doing a third at the worlds in Beneteau 25[4] and winning other recognized regattas.

Three years ago I jumped to the 470 class. Now I'm sailing in 470 five days a week and racing around Europe improving and learning every day.

Sailing in 470 I've seen that's a cool boat but it's partially obsolete in what technology respects.

I'm close to the class and to the boat and as a 470 sailor I could get the opinion of many sailors about the boat and know how actually the 470 class is worldwide. And I think, that for ensure the future of the 470 in the forthcoming Olympic games and to continue being a reference class in sailing, the boat design should be performed.

So moved by the fact of being a 470 sailor and by the interest in boat design I decided to tackle the problem and study it. Proposing a new remodeled 470, which maintain the essence of the design and place it again in the vanguard of boat design the forthcoming years.

[1] CMV: Centre Municipal de Vela, a sailing school in Barcelona.

[2] L'Equipe: It's a double handle dinghy for children under 16 designed by the french Marc Laurent.

[3] 420: It's worldwide performance two person trapeze and spinnaker racing dinghy.

[4] Beneteau 25: Monotipe keel boat of 25ft. designed by Farr Yacht design.

2. The 470

The 470 is a dinghy designed by Andre Cornu, a French 505 sailor and a boat designer, in 1963 as a modern fiberglass planing dinghy which lure sailors of different ages and sizes.

The boat is a two crew high performance planing dinghy with centerboard and *bermudan rig* equipped with spinnaker and a single trapeze. It has a large sail area to weight ratio and is designed to plane easily.

It's tactically demanding and requires fluid coordination between the skipper and crew. A light and narrow boat responds easily and immediately to body movement. The 470 is cushy to handle, but to be competitive, every aspect should be mastered to perfection.

In 1969, the 470 Class achieved the status of an International Class from the IYRU[5] and in July 1970 the first 470 Class World Championship was organized on the lake of Lacanau with 51 boats from 14 nations and 3 continents and since then a Championship event have been celebrated every year, achieving astonishing amounts of boats and many represented nations.

In 1972 the International Yacht Racing Union selected the 470 for the double-handed dinghy event open to both men and women sailors for the 1976 Olympic Games of Montreal. Since that time 470 Olympic events have been renewed every four years and since 1988 the open event was split in two, one for men crews and one for women crews.

Nowadays there are more than thirty-eight thousand 470 sailors spread in 75 different countries.

After 47 years many things has changed around the 470. People sails as a professionals, the technology has been developed to an unbelievable level, the materials are completely reinvented and the training methods and regattas make use of new technologies, but the boat and its construction hasn't changed.

The hull is build with 1960's era materials[6], the sails were designed considering the skills in those times and using old materials and all the boat is build using old methods and designed thinking those times requirements. It's true that over the years small things has changed in the boat, like ropes, systems, and the quality of these old materials, but is this enough?

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[5] IYRU (International Yacht Racing Union): was the institution that englobes all the sailors, the classes and the national federations. In 1996 the IYRU change its name to the International Sailing Federation.

[6] Materials will be seen in more detail in chapter 9

3. The 470 Nowadays

Let's investigate what say the Class and some recognized sailors about the 470.

Basically 470 Class use these keywords to define the boat[7]:

Dynamic

Global

Physical

Challenging

Exhilarating

Let's see how considering these keywords dictionary definition they link them with the boat and then we'll ask ourselves if the boat satisfies the definition and if we can do something to improve it.

<u>Dynamic:</u>

The dictionary says ....

characterized by force of personality, ambition, energy, new ideas, energetic; vigorous; forceful.

1.Australian 470 sailing. Source: www.470.org

7 These keywords, the dictionary definition, the class opinion, the sailors opinion and the pictures of this chapter are directly abstract from the 470 class web page.

We say (the class) ....

The 470 is full of energy and continues to attract the next generation of sailors.

And the sailors say ....

Joe Gianfield (GBR): *" I love the 470. It's very well-rounded class. The knowledge you need to be successful - you need everything - the tactical element, the technical side and the technique is all challenging. It's a boat that incorporates every aspect of dinghy racing."*

Kevin Burnham (USA): *"The 470 is a dynamic boat for many reasons. First and foremost is the intrigue into setting the boat up to race. Regardless of your personal size in weight and height, the 470 allows everyone to be competitive in all conditions because of this versatility in being able to adjust and balance the rig to your physical stature. Next is the competitive nature of the sailors that race the 470. Former 470 sailors are abound in the America's Cup and big boat races around the world."*

My point of view is that the 470 as Joe and Kevin said is completely dynamic in what sailors refer. There aren't limitations in sailors' weight or height, and people are very competitive. But what about the boat? Does it have a dynamic personality? I think we can bring new ideas and do the boat more energetic. We can also show ambition to improve and show how dynamic the class and the boat is by updating the boat.

<u>Global:</u>

More than 38 thousand active sailors spread in 75 different countries, 59 National Class Association and expanding, many plans and helps in developing countries, a labored website and an important media campaign.

My point of view: All this changes are interesting and necessary but new ways of promoting the regattas are necessary to attract public. Why doesn't build a boat with inboard media facilities? And affordability is also important. So why doesn't make a more affordable boat?

<u>Physical:</u>

The Dictionary says ...

involving or characterized by vigorous bodily activity

2.Australian 470 sailing upwind. Source: www.470.org

We say (the Class) ...

You will not be sitting around on the 470. A highly boat that responds swiftly to the demands of the sailors. An athletic class it certainly is and represents well the many physical dinghy classes around the world.

And the sailors say ...

Kevin Burnham (USA): " There is no doubt that you must be in good physical condition to race a 470 competitively. Whether you are driving and hiking or trapping and hanging on a wire, you must be in good physical shape to do both."

My point of view is that 470 is and athletic class but I'm not sure if it responds to the demands of all the sailors. We can increase the boat acceleration and reach high speeds downwind with some changes.

Challenging:

The Dictionary says ...

anything, as a demanding task, that calls for special effort or dedication

3. 470 sailing upwind in heavy conditions. Source: www.470.org

We say (the Class) ...

Sailing isn't just about going fast, or from one point to another - although for many the simplicity of speed is very attractive. The 470 is about speed - and more.

The 470 represents the alluring sailing challenge of tactics, technique, individual boat tweaking to make your boat go faster. It is about the individual athlete's sailing skills and their teamwork.

And the sailors say ...

Marcelien de Koning (NED): "If you can sail the 470 you can sail any big boat, because you understand the racing, all the tactics involved. It is a superb boat to learn how to sail tactically and strategically."

My point of view is that we can make the boat more spectacular keeping the tactics and challenging us (the sailors) with new things in technical aspects.

Exhilarating:

The Dictionary says ...

causing strong feelings of excitement and happiness.

4. Dutch 470 sailing happily upwind. Source: www.470.org

We say (the Class) ...

The 470 is a fun boat to sail, it is quickly on the plane and provides an exhilarating ride.

And the sailors say ...

Kevin Burnham (USA): *"The 470 is an exhilarating ride. It will plane upwind in 10-11 knots of wind. Get reaching with just the rudder in the water in 20 knots and blast you into the atmosphere in over 25 knots!"*

My point of view is that if we smile when we plane, when we surf a wave or when we speed up why doesn't do it often? Let's do these feelings stronger!

As we could see, the 470, as a class, satisfy all the keywords. Although by adapting the boat we can reinforce these keywords and make the boat express this words itself. And this is one of my goals.

4. The 470 at the Olympics Games

The 470 is an Olympic class, and in great measure the success through the time and popularity is because its presence of the 470 in Olympic Games. Therefore we're going to analyze the Olympic necessities and requirements in order to improve the boat to perform best Olympic targets.

As an Olympic class, should reflects and perform the values and necessities of the Olympic Spirit. Mainly exist three Olympic values:

- Excellence
- Friendship
- Respect

The **Excellence** means giving your best, on the field of play or in the professional. It's not only about winning, but also about participating, making progress against personal goals, striving to be and to do your best in our daily lives and benefiting from the healthy combination of a strong body, mind and will.

The **Friendship** value encourages us to consider sport as a tool for mutual understanding among individuals and people from all over the world. The Olympic Games inspire humanity to overcome political, economic, gender, racial or religious differences and forge friendships in spite of those differences.

And **Respect** which incorporates respect for yourself, for others, for the rules and regulations, for sport and the environment. Related to sport, respect stands for fair play and for the fight against doping and other unethical behavior.

It's clear that the 470 reflects these values in his sailors. Excellence is indispensable to be at the top, day by day 470 sailors learn to beat their-self to beat others and mind and body should be perfectly well connected to accomplish the target. Friendship isn't less present in the class, sailors find themselves in extreme situations where they should respect and fit perfectly with the partner and then they sail worldwide against others and they make relationships between them too, working together to practice and achieve results. And Respect is included by the fact that sailors must respect the racing rules while sailing and respect each other.

I only would like to add that by some improvements and modifications we can reinforce these values.

On the other hand the ISAF (International Sailing Federation) have a criteria for selecting Events and Equipment in the Olympics which must:

i. Allow athletes around the world, male, female and of different sizes and weights to participate.

ii. Give the best sailors in each country the opportunity to participate in readily accessible equipment.

iii. Combine both traditional and modern events and classes, to reflect, display and promote competitive sailing.

iv. Include at least two events for men and two events for women designed to maximize excitement, innovation, public and media appeal.

v. meet the international Olympic Committee's criteria (if any) for participation in the Olympic Program and achieve the current International Olympic Committee's objective (if any) for the minimum level of participation for women.

And if we modify the boat we can achieve an affordable version and get a design in harmony between modernity and tradition. With media success and attracting public.

5. The 470 keys to success

After seen the current situation of the boat we can consider which changes fit best but before that, I would like to add some strong points in the 470 success and think over them.

1. Nowadays, the 470 is sailed in more than 75 countries, with 38.000 boats all over the world and this is the ideal equipment to ensure and assist in the continued growth of Nations and Sailors competing. We must consider that all the changes will affect large quantity of people and will take time to apply.

2. 470 can provide exciting racing within the possible new Race Formats by sailors of common body types in young athletes (46-76kgs and 150-190cms), importantly in all sea conditions from 5 knots to 40 knots. We must maintain this wide range of weight, stature and sailing conditions.

3. Attract nations of all sizes, but importantly Developing and Small Nations, to invest in competitive sailing in readily available and reasonably priced equipment. It's not an expensive boat compared with others but I'm sure that can be cheaper.

4. Fair racing is protected by strongly enforced One Design Class Rules and Measurement standards. It's possible to reinforce this fair racing, looking for more material equalities between teams.

5. The Class Association is well organized with Professional support staff and an efficient and active promotional and media plan. This media plan can evolve to a new step in sailing by providing the boat with media facilities.

6. The Improvement Targets

We have gone through the different aspects that influence the boat so it's high time to define the ideal improving targets for the 470.

There are 7 words that I think the 470 should improve to fit best in the current sailing world situation:

Speed

Acceleration

Agility

Comfort

Compact

Media

Affordability

I'm not sure if we could get all the targets at once, but we are going to seek improvements to each one and then we are going to put it together and choose the one's which set in best.

Let's see broadly which are going to be the improvement targets.

<u>Speed:</u> can be boosted by increasing the sail plan area and by reducing the drag. The target would be a high performance speed boat which means that the dinghy must be able to sail faster off the wind, than the wind.

<u>Acceleration:</u> can be improved by adapting the sails to new shapes and redistributing the weights in the boat or even changing the boat weight.

Agility: Faster maneuvers using new systems.

Comfort: Distribute the deck in a new way to make boat easy to sail.

Compact: Create transport facilities solving current problems like mast length.

Media: Create specific spaces to place media tools like cameras or a GPs.

Affordability: Control the costs, even reducing the current price of the boat.

In the next chapters I'm going to tackle these issues. Off course during this process the boat will suffer some changes but I'll ever maintain the spirit of the boat and the water lines that are the essence of the 470.

7. The Sails

I think that the first point we should focus in, are the sails. The sails are the elements which most affect the stability, the speed, and the acceleration of the boat.

In this chapter I'm going to begin introducing the different properties of a sail and then I'll think about how they work in order to obtain some conclusions that will define the final materials of the sails and their shapes.

I must consider that the boat is directly affected by any changes in the sail plan so I must maintain the proportion between the jib and the main to not change the feeling and behavior of the boat while sailing.

How a sail should be?

When we talk about design a sail, we should control two aspects from which depend on a good final shape and a good performance of the sail. These are:

The Sailcloth Characteristics

The Sail Geometry

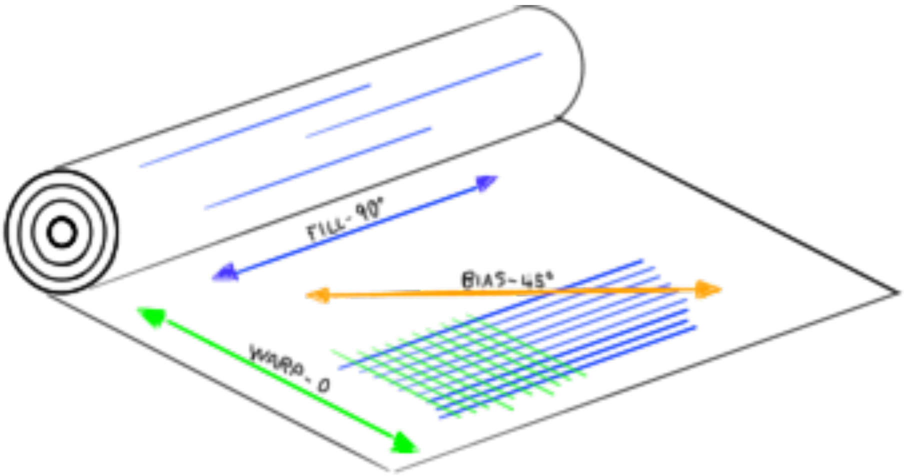
The Sailcloth Characteristics

The Sailcloth Characteristics will define the durability, the weight, the resistance, the stretching, the efficiency and the leading shape of the sail.

The sailcloth properties are:

- Cloth Geometry (Warp, Fill, and Bias)
- Stretch resistance
- Strength
- Cloth weight
- Flexibility
- Porosity
- Water absorption
- Ultraviolet stability

- Cloth Geometry (Warp, Fill, and Bias): The **warp** is the longest direction in a roll of fabric, the **fill** directions is parallel to the filling yarns and are perpendicular to the warp, the **bias** direction bisects the other two at a 45-degree angle to each. The important aspect of the bias direction is that in almost all applications yarn never runs parallel to it, and without this direct support, the cloth is much more likely to stretch when pulled in the bias orientation. So we should know the stretch direction of the sail in the studied area quite well and then choose and orient the cloth properly.



5. Cloth directions. Own Source

- Stretch resistance: consist in resist the stress generates by the wind when the sail is in use. Usually it's more important than strength for mainsails and headsails. Stretch resistance can have different values in different directions in the fabric. It can also be dependent on time, some materials when initially loaded, will stretch little, but if the load is maintained over a long time, they will gradually elongate. **Creep** is the engineering term that describes a nonrecoverable stretch elongation. Stretching is caused by geometric reasons or by the elongation of the fibers. **Crimp** is a type of geometric stretch that refers simply to the serpentine path that yarns must take in crossing over and under other yarns in a weave or a knitted construction. Another type of geometric stretch is **bias stretch,** the simply deformation of the weave that causes the warp and filling to cross at other than right angle. We must consider the stretch resistance because it will define the rang of wind in which the sail will sail and its durability.

- Strength: There're two kinds of strength, the breaking strength, that is the point where the material broke, and yield strength that is the dividing line between elastic elongation and permanent elongation. When we design a sail the idea is to no cross the yield strength point.

- Cloth Weight: We should consider the weight aloft. But by far the most important consideration of weight is shape. In light air, the shape of a sail can suffer simply because the sail is sagging under its own weight.

- Flexibility: is determined by a combination of factors, including the stretch of the fibers used and the thickness and weight of the material. In racing sails, flexibility is often sacrificed to achieve lower stretch. Some laminated sail cloths are known to shrink with use because of their lack of flexibility. The material doesn't literally shrink, but appears to because thousands of small wrinkles and buckles cause it to contract.

- Porosity: In light winds and lumpy seas, the more porous spinnaker seemed to hold its shape better. In any other conditions zero porosity is much interesting.

- Water absorption: is certainly a problem for some sailcloth. If the sail absorbs water, it becomes heavier and more difficult to trim.

- Ultraviolet stability: UV radiation from the sun can break the molecular chains and weaken the materials in sailcloth.

The emphasis in modern sailmaking is to determine the direction of the forces in a sail through stress maps, and then correctly orient the strong fibers to resist the forces.

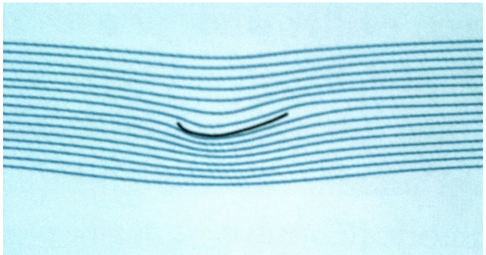
I think that development in sailcloth is good and should exist. It has no sense to use the same materials used more than forty years ago. I agree that the development should be "controlled" to avoid a continuous evolution that can effort few people. But by using a rule that restrict material we just get an evolve in that material/s and with this we're reducing the opportunity to evolve to best materials with best durability, best efficiency, greener and best in cost.

So, because of these reasons I'm going to leave the sailcloth material and the process of manufacturing of the sails open, just restricting a minimum cloth-weight based on the current weight and limiting the number of sail sets used in regattas per year to: 1 main, 2 jibs and 3 spinnakers.

The Sail Geometry

To take decisions about the sail geometry we are going to think over how a sail works. Defining step by step the best shape to achieve the best performance.

A sail is a section with a defined camber that interacts with the wind around it.



6. Flow streamlines around a sail section. Source: Aero-Hydrodynamics, Fabio Fossati

What the sails do is modify the stream wind course and by Bernoulli principle is created a pressure difference between the two sides of the sail.

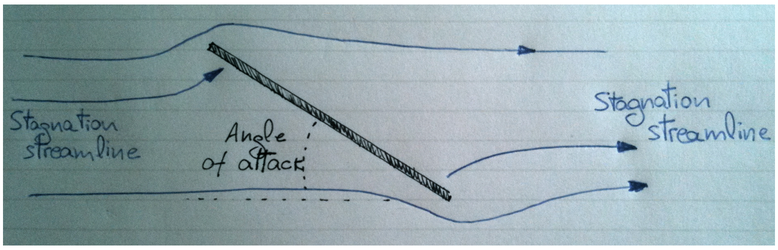
That doesn't mean the sail is like an airplane wing. Usually people believe that, and believe airplanes fly because air passing over the curved upper surface of its wings has to travel a longer distance than the air passing under the flat lower surface and since it has to go farther, it has to go faster to reach the trailing edge at the same time as its "brother" particle. This difference in distance causes a difference in speed that causes a difference in pressure. But if we ask ourselves why can an airplane fly upside down? And if think that sail has the same surface in each side you will realize that a sail is not really like an airplane wing at all because:

1. In sails the thickness is absolutely negligible.
2. The fabric that sails are made from can only respond to tensile force but not to compression, so it is deformed when subjected to wind loads. This means that the shape of the sail will depend not only on how it's trimmed but also on wind strength.
3. The material sails are made from may be porous.
4. The material sails are made from has a rather irregular surface.

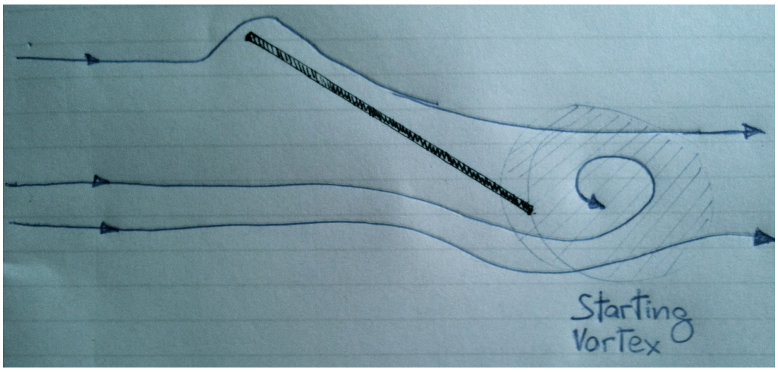
So for a sail, the difference in distance can't be the cause of lift. In fact, if you put a perfectly flat board at an angle to wind, there will be lift.

Here is when the circulation theory appears.

When we pull a flat board a certain angle, giving it an angle of attack the flow tries to make the turn around the trailing edge, but because of viscosity, it trips, and the starting vortex forms.



7. Symmetrical airflow without viscosity. Own Source

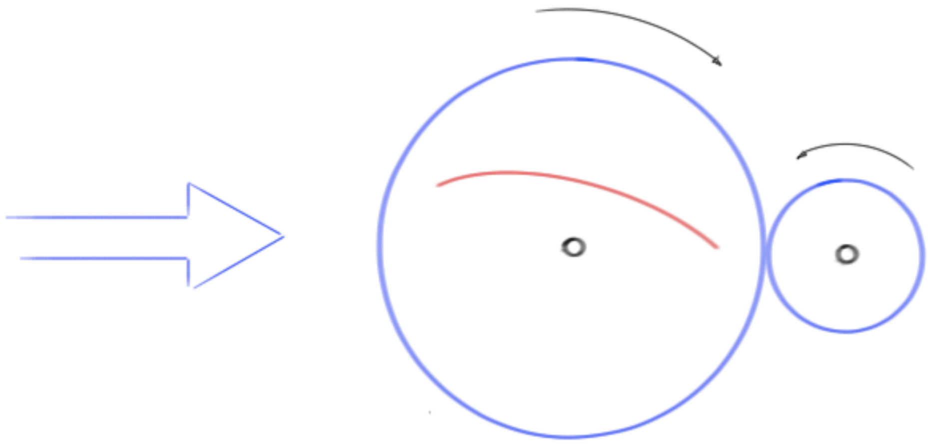


8. Airflow with viscosity referring to starting vortex. Own source

Without viscosity, you will recall, the air on the windward side is able to turn the trailing edge. With viscosity, however, the air on the windward side attempts to turn the trailing edge but doesn't make it. It separates, causing a swirl of air to form, and then this swirl, or starting vortex, creates the circulation flow.

Circulation is a special mathematical solution where a second flow rotates around the airfoil. The circulation flow is greatest near the foil and progressively less moving away from it. In the mathematical solution, circulation air speeds are adjusted so that the Kutta condition[8] at the trailing edge, or leech, is satisfied; that is, the calculated airflow speeds and pressures are the same off both sides of the trailing edge.

[8] Kutta condition: A body with a sharp trailing edge which is moving through a fluid will create about itself a circulation of sufficient strength to hold the rear stagnation point at the trailing edge.



9. The starting vortex (the small wheel) turns the circulation. Own source.

On the top of the airfoil, the circulation flow is in the same direction as the normal, or non circulating, flow. This means that the two flows are added together, resulting in a higher-speed flow. On the bottom side, however, the circulation direction is against the non circulating flow, so the two flows cancel each other somewhat, resulting in a slower-speed flow. On the top (leeward) side, this complementary action gives high speed and low pressure; on the bottom (windward) side, this opposing action gives low speed and high pressure. This is the recipe for lift.

Circulation alone can't cause lift, exactly in the same manner as the linear, or non circulating, flow can't cause lift. The recipe for lift requires that the two flows be added together on the top, or lee side, of the foil, and the two flows somewhat cancel each other out on the bottom, or weather, side. This gives the speed differential, top to bottom, the pressure differential, and then the lifting force.

To get that big wheel up to full speed also takes time. The larger the sail plan, as measured by its average chord length, the larger the circulation is and, hence, the longer it will take for the lift to build. On the other hand, the more wind available to turn the crank, or starting vortex, the faster the circulation flow gets up to speed, and the faster the lift on the sail builds.

So a sail with high aspect ratio will achieve this properly circulation faster than low aspect ratio sail.

The relative aspect ratio of sails, are they short on the foot and tall on the luff (high aspect ratio), or long on the foot and short on the luff (low aspect ratio). The aspect ratio of a sail is computed by dividing the luff by the foot.

There's another matter related with the aspect ratio, it's the induced drag.

As we know, the air on the windward side is generally at a higher pressure than the air on the leeward side, and in an attempt to reduce the pressure differential, the high-pressure air leaks over the top and under the bottom of the sail. That's induced drag. So the higher the aspect ratio, the smaller the pressure loss round shorter foot and head in comparison with the rest of the sail area.

In general we can say that sail plans with high aspect ratios are more efficient in that the induced drag for a given quantity of lift produced is inversely proportional to the aspect ratio.

Otherwise we should consider that there isn't just one sail on board and between them exist a close relation. What's named slot effect.

The slot effect theory says that since there is less area between the leech of the jib and the front of the main than between the headstay and the mast, the flow through the slot is speeded up. But let's view the slot-effect theory in terms of circulation. The jib and the main have their own circulation fields. The two circulation fields oppose and tend to cancel each other in the slot. Thus, there is not the accelerated air speed that the old theory promises. Much of the air that one might think goes in the slot is actually diverted by the combined circulation fields so that it goes on the lee side of the jib. This is upwash[9].

The fact that the stagnation streamline of the jib is now much farther to windward shows that much more of it is being deflected around the lee side of the headstay so therefore the lee side of the jib. So besides a lift, the mainsail gives the jib more wind on its lee side, or to put it another way: increased velocities.

The main has one final contribution to give to the headsail, that is, increased velocities at the trailing edge. We know that to satisfy the Kutta condition, the velocity at the leech of the mainsail must be equal on both sides and near to the speed of the normal, or free-stream, wind. This is true for the mainsail, typically the last sail in the sail plan, but it is not true for the jib. The leech of the jib ends in a relatively high-speed area: on the lee side of the mainsail and Kutta condition is satisfied at a higher speed that blends the jib flow with the high-speed flow created by the mainsail in the region of the leech of the jib. The speed at the jib's leech is about 30% higher than the free-stream speed.

And because of that, we should try to have the leech of the jib at the point where the speed flow of the mainsail is maximum. But never should exist much overlapping between

[9] Upwash: The air "senses" that the sail is coming and bends to leeward in anticipation of it; the water senses that the keel is coming and bends in anticipation of it.

the jib and the mainsail because it would be unfavorable if we consider the circulation around both sails.

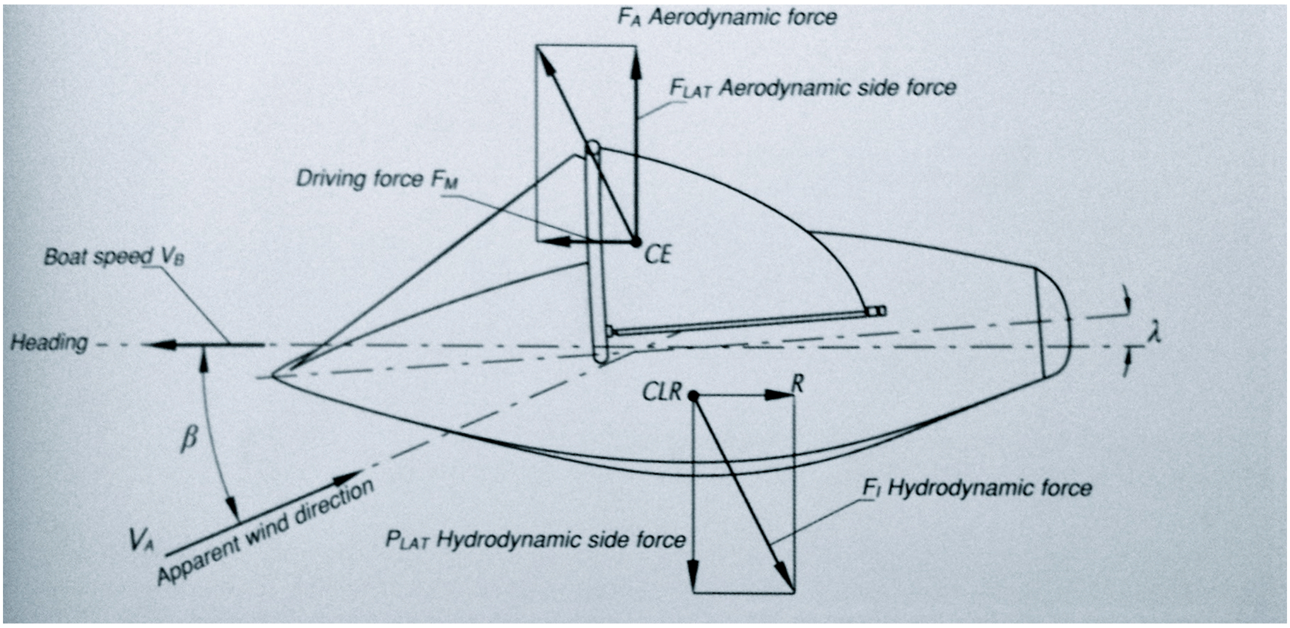
Once we know the basics of how a sail works and which are the relation with his partner we're going to reflex about the requirements on sailing about sails.

- Close-hauled: The essential requirement of a sail is to generate a large driving force component, F_M. But it cannot do that without producing at the same time a heeling force, F_H.
- Reaching: When a boat begins to bear away from close-hauled, the close-hauled criteria become gradually less stringent. Sails generate less and less heeling force off the wind.
- Running: On downwind courses the only criteria for sail efficiency is maximum drag of the rig, because the driving force is equivalent to be exposed to the action of the wind.

Let's study the two extreme cases, close-hauled and running.

A sailing boat is in essence a physical system that interacts simultaneously with two fluids through the forces of the wind and the sea. In extreme synthesis, we can say that this physical system is made up of components that are closely interconnected (hull, appendages, sails and rigging).

Since the boat sails partly immersed in water and with the remaining part immersed in air, it's subject to force we will call hydrodynamic and aerodynamic respectively.



10. Description of the general forces on the yacht from above. Source: Aero-Hydrodynamics, Fabio Fossati

If we analyze what happens between the yacht and the air surrounding her. The action of the apparent wind V_A on all parts of the boat above the waterline (hull, rigging and sails) through the basic mechanisms that govern the interaction between a fluid and a solid object produces an aerodynamic force F_A. We can see that this force is applied directly to a single point of the boat called the centre of the sail plan or aerodynamic centre of effort[10] (CE).

This force has a component in a direction perpendicular to that from which the apparent wind is blowing (Aerodynamic lift P_A) and a component in the direction from which the wind blows (Aerodynamic resistance R_A).

Depending on which apparent wind direction those components will change. When sailing close hauled, we use fairly small angles of attack and the aim is to produce as much lift as possible, while as we sail further off the wind job of the sails changes, because drag component becomes very important and the aims become producing as much aerodynamic force as possible.

Back to the situation below the waterline, we discover that the appendages too play a role analogous to that of the sails. In fact, over the keel, the rudder and the bottom of the boat there is a flow in relative motion, and they behave as if they were the wings of an airplane flying in the water.

The result of this interaction between the boat and the water surrounding it's the creation of a hydrodynamic force F_I applied to a point of the bottom called the centre of lateral resistance[11] (CLR).

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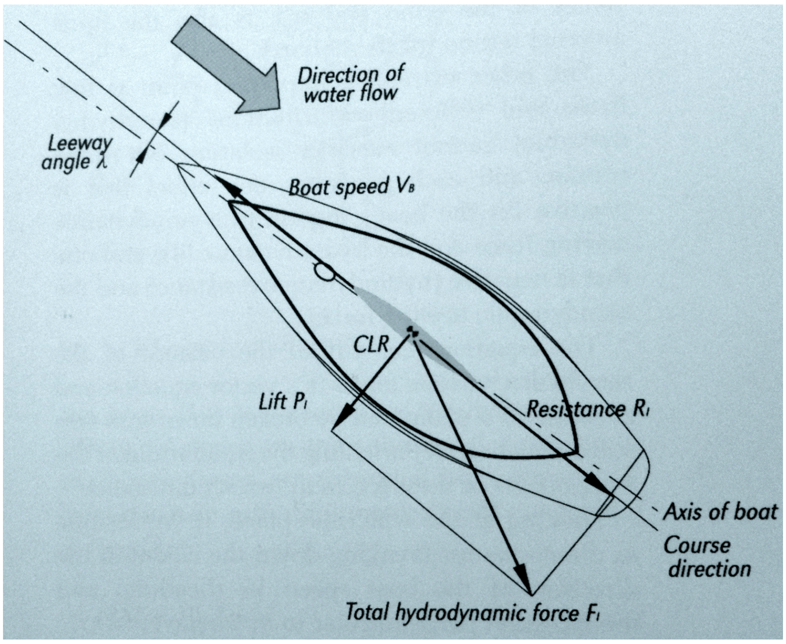
[10] Centre of effort: We are going to assume that the centre of effort is the geometrical centre of the sail area. Because, although the actual position of this point is a function of whole series of variables, including the way in which the yacht's sails are trimmed, our interest bases on compare different sail geometries but not do subsection in the sails shape so it's just important to find CE in the same way in all the models to compare.

[11] CLR: As in CE in order to simplify matters we assume that the CLR coincides with the geometrical centre of the longitudinal section of the submerged part of the boat.

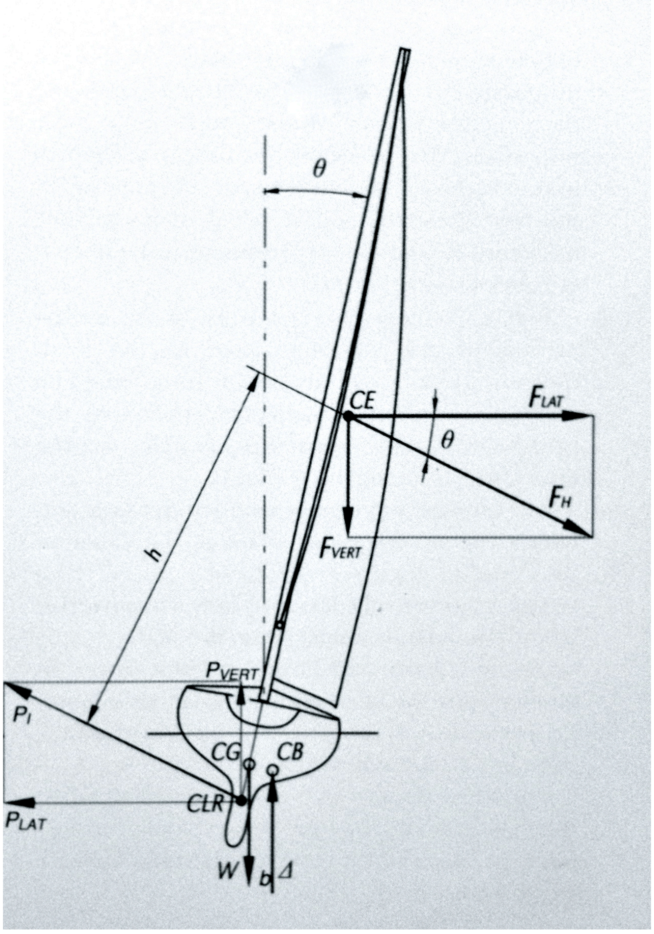


11. Interaction of the water flow with the submerged part. Source: Aero-Hydrodynamics, Fabio Fossati

Because of the side force (Flat) on the sails, the direction of the course followed by the yacht will be deviated downwind of the fore-aft axis by an angle called the leeway angle.

This angle thus represents the angle of attack with which the flow of water invests the submerged part of the boat, shown in the picture above.

In a way that is quite analogous to what happens with the aerodynamic force, the hydrodynamic force F_I can be broken down into two components whose directions are respectively that of the relative flow speed, which in the absence of current is exactly the opposite of the boat speed V_B and is called hydrodynamic resistance R_I, and the perpendicular to V_B, known as hydrodynamic lift P_I.



12. Panorama of the forces applied to a boat under way. Source: Aero-Hydrodynamics, Fabio Fossati

We can now put together the aerodynamic and hydrodynamic effects. When the boat is under way the aerodynamic forces must balance the hydrodynamic forces. The motion of the yacht is governed by the dynamic equilibrium of the forces applied to it.

For these reasons of equilibrium, then, when the boat is under way the aerodynamic force F_A must be balanced by the hydrodynamic force F_I, so we must have:

$$F_A = F_I$$

And this concludes that to maintain the feeling and this equilibrium while sailing close-hauled we should maintain the CE in the same longitudinal axis and we must control how much varies in vertical axis.

Another important thing in a sail are the battens. Battens influence the shape of the main. Their reason for being is to support extra cloth out from the sail. Without battens, the extra cloth beyond the straight-line measure from head to clew has a tendency to fold over itself. This extra material, called roach, can be supported without battens by precisely balancing the shaping in the back of the sail. It is, however, and extremely delicate balance. Battens support the roach by cantilevering the extra area. The connection between batten length and roach is direct. In the interest of increased speed we use full-battens which allow a longer roach and thus more sail area.

The full-battens have these advantages and disadvantages which are:

Advantages:

· The sail durability is improved because of reduced flogging.

· Quieter because of reduced flogging.

· Easier to flake on boom.

· Very smooth shape.

· Able to hold shape well, even in light air and chop.

· Structural rigidity allows projection of more area.

· Allows a sail that doesn't need as much vang tension for appearance's sake as well as performance.

Disadvantages:

· Added weight.

· Slides jam due to inward pressure of battens, leaving the sail partway up or down.

· Require special, batten-pocket ends and luff hardware.

· Chafe against the shrouds when running or broad reaching.

The conclusion for battens issue is that full-batten are best to increased speed and on the other hand will be quite necessary if we have high-ratio sails. So the best option will be to limit the number of battens on each sail.

Finally, knowing that drag should be maximize downwind the best way to achieve it is maximizing the sail area, therefore we will increase the sail area as much as we can especially the spinnaker.

Conclusion of the Sails theory.

So from this review about sails we can conclude we should use:

- Any material which provide durability, efficiency, respectable environment and low cost. Restricting the weight which has to be similar to current sails and the number of sails used per year.
- High aspect-ratio sails because are more efficient.
- A jib with the leech at the point where the speed flow of the mainsail is maximum but never with much overlapping with the main.
- Sails that maintain the CE in the same longitudinal axis.
- Sails with battens just limiting the number on each sail and allowing the use of full-battens.
- Bigger sails especially the spinnaker.
- And to make it more appealing I decided to use red-colored seams and finishes and make gold the 470 sail logo.

The next pages are the new 470 sails rules based on the conclusions above. In the appendix 1 you can find the complete new versions rules and the current rules in order to compare them[12].

After make 6 preliminary versions and trying to combine best the sails I decided to keep two versions: the V1 version which maintain the same mast, and the V3 which is designed thinking in use another mast that will be developed in the coming chapters. The V3 due to it's a larger sail plan incorporates a reef system for heavy wind conditions.

Changes in the rules are in red to ease the reading.

[12] The pictures include in the rules come from the current rules, defined by the 470 class.

V1 Sails Rules

Section G - Sails

G.1 PARTS

G.1.1 MANDATORY

(a) Mainsail

(b) Headsail

G.1.2 OPTIONAL

(a) Spinnaker

G.2 GENERAL

G.2.1 RULES

(a) **Sails** shall comply with the current **class rules**.

(b) Headsails may be measured with battens inside the **batten pockets**.

G.2.2 CERTIFICATION

(a) The **official measurer** shall **certify** mainsails and headsails in the **tack** and spinnakers in the **head** and shall sign and date the **certification mark**. Sails may be certified without identification on them.

(b) Sails shall carry the sail sticker issued by the ICA attesting that the class fee has been paid, and located for mainsails and headsails in the tack and spinnakers in the head.

(c) The ISAF or an MNA may appoint one or more **In-house Official Measurers** to measure and **certify sails** produced by that manufacturer.

(d) Not more than 3 sails for year can be certificated by a sailor. In case of doing 6 or more events from the ISAF Sailing World Cup and the worlds the limit will rise up to 4 sails for each sailor. The sailors shall be ICA members.

G.2.3 SAILMAKER

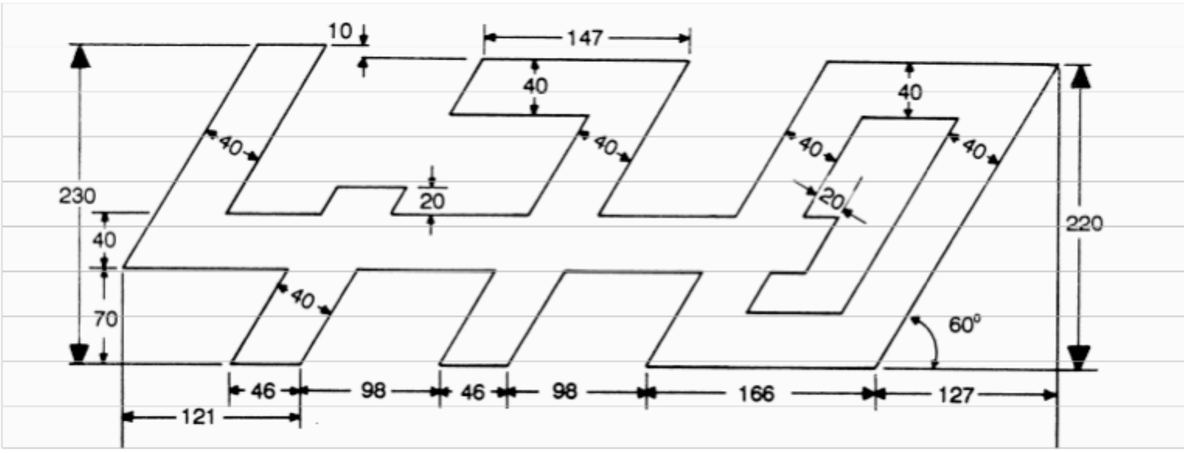
(a) The sailmaker is optional.

G.3 MAINSAIL

G.3.1 IDENTIFICATION

(a) The mainsail shall carry the 470 insignia in gold paint or other durable material, securely attached. People who have sailed an Olympics could attached the Olympic rings behind the insignia.

(b) The 470 insignia shall be placed under and in proximity to the upper batten pocket and shall conform to the Figure “470 Emblem” with a tolerance of 2 mm.



470 Insignia

G.3.2 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.3.3 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The **sail** shall have four **batten pockets** in the **leech.**

(c) The **leech** shall not extend aft of straight lines between:

(1) The **aft head point** and the intersection of the **leech** and the upper edge of the nearest **batten pocket,**

(2) the intersection of the **leech** and the lower edge of a **batten pocket** and the intersection of the **leech** and the upper edge of an adjacent **batten pocket** below,

(3) the **clew point** and the intersection of the **leech** and the lower edge of the nearest **batten pocket.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, headboard with fixings, cunningham eye or pulley, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** boom slide fixed at the **clew,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.3.4 DIMENSIONS

	minimum	maximum
Leech length		6000 mm
Quarter width		2000 mm
Half width		1900 mm
Three-quarter width		1800 mm
Top width		1400 mm
Foot length		2100 mm
Thickness of the **body of the sail**	0.165 mm	
Distance from **clew point** to **foot** bolt rope		60 mm
Distance from **tack point** to **foot** bolt rope		300 mm
Window to **sail edge**	150 mm	
Weight	2.5 kg	

G.4 HEADSAIL

G.4.1 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.4.2 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The headsail shall have a maximum of three **batten pockets** in the leech.

(c) The **leech** shall not extend beyond a straight from the aft **head point** to the aft of the first **batten pocket** and from the aft of the first **batten pocket** to the **clew point.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.4.3 DIMENSIONS

	minimum	maximum
Luff length		4500 mm
Leech length from the head sail to the first aft point of the batten pocket		340 mm
Leech length from the aft point of the batten pocket to the clew		3910 mm
Foot length		2200 mm
Foot median		4300 mm
First batten width		180 mm
Top width		30 mm
Foot irregularity		30 mm
Weight	0.9 kg	

G.5 SPINNAKER

G.5. MATERIALS

(a) The fibres shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

G.5.1 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The following are permitted: Stitching, glues, tapes, corner eyes, tape eyes, tell tales, sail shape indicator stripes, sail identification, sail-maker labels, sail sticker, **certification mark.**

G.5.4 DIMENSIONS

	minimum	maximum
Luff lengths		4660 mm
Foot length		3000 mm
Foot median		5100 mm
Difference between diagonals		50 mm
Upper width (upper leech points at 200 mm from head point)		350 mm
Half width		3450 mm
Three-quarter width		1830 mm
Weight	0.6 kg	

V3 Sails Rules

Section G - Sails

G.1 PARTS

G.1.1 MANDATORY

(a) Mainsail

(b) Headsail

G.1.2 OPTIONAL

(a) Spinnaker

G.2 GENERAL

G.2.1 RULES

(a) **Sails** shall comply with the current **class rules**.

(b) Headsails may be measured with battens inside the **batten pockets**.

G.2.2 CERTIFICATION

(a) The **official measurer** shall **certify** mainsails and headsails in the **tack** and spinnakers in the **head** and shall sign and date the **certification mark**. Sails may be certified without identification on them.

(b) Sails shall carry the sail sticker issued by the ICA attesting that the class fee has been paid, and located for mainsails and headsails in the tack and spinnakers in the head.

(c) The ISAF or an MNA may appoint one or more **In-house Official Measurers** to measure and **certify sails** produced by that manufacturer.

(d) Not more than 3 sails for year can be certificated by a sailor. In case of doing 6 or more events from the ISAF Sailing World Cup and the worlds the limit will rise up to 4 sails for each sailor. The sailors shall be ICA members.

G.2.3 SAILMAKER

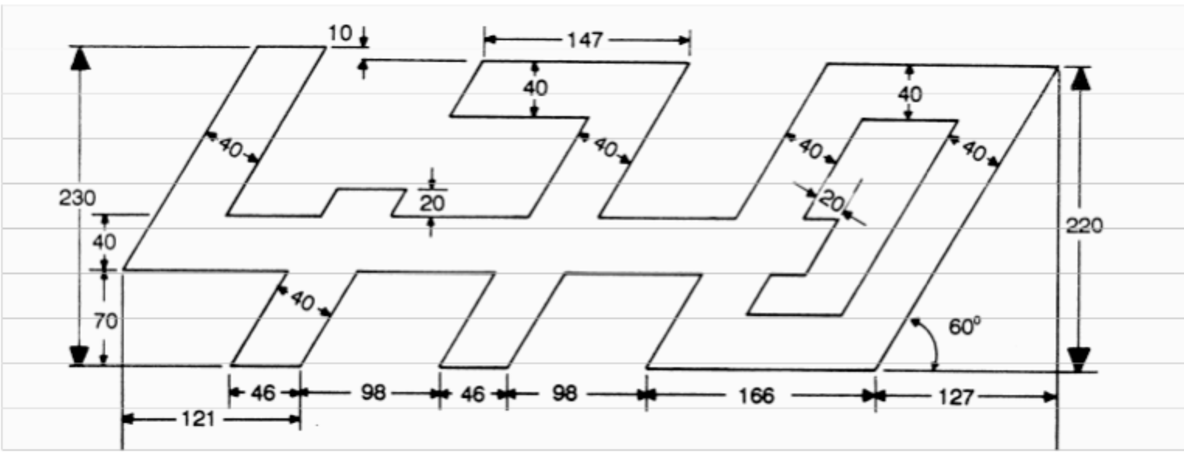
(a) The sailmaker is optional.

G.3 MAINSAIL

G.3.1 IDENTIFICATION

(a) The mainsail shall carry the 470 insignia in gold paint or other durable material, securely attached. People who have sailed an Olympics could attached the Olympic rings behind the insignia.

(b) The 470 insignia shall be placed under and in proximity to the upper batten pocket and shall conform to the Figure "470 Emblem" with a tolerance of 2 mm.



470 Insignia

G.3.2 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.3.3 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The **sail** shall have six **batten pockets** in the **leech.**

(c) The **leech** shall not extend aft of straight lines between:

(1) The **aft head point** and the intersection of the **leech** and the upper edge of the nearest **batten pocket,**

(2) the intersection of the **leech** and the lower edge of a **batten pocket** and the intersection of the **leech** and the upper edge of an adjacent **batten pocket** below,

(3) the **clew point** and the intersection of the **leech** and the lower edge of the nearest **batten pocket.**

(d) A reefing system reducing maximum 25% of the luff length of the sail. It can be done or undonev just once while racing.

(e) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, headboard with fixings, cunningham eye or pulley, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** boom slide fixed at the **clew,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.3.4 DIMENSIONS

	minimum	maximum
Leech length		7000 mm
Quarter width		2480 mm
Half width		2200 mm
Three-quarter width		1900 mm
Top width		1500 mm
Foot length		2650 mm
Thickness of the **body of the sail**	0.165 mm	
Distance from **clew point** to **foot** bolt rope		60 mm
Distance from **tack point** to **foot** bolt rope		300 mm
Window to **sail edge**	150 mm	
Weight	3 kg	

G.4 HEADSAIL

G.4.1 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.4.2 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The headsail shall have a maximum of four **batten pockets** in the leech.

(c) The **leech** shall not extend beyond a straight from the aft **head point** to the aft of the first **batten pocket** and from the aft of the first **batten pocket** to the **clew point.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.4.3 DIMENSIONS

	minimum	maximum
Luff length		5200 mm
Leech length		4900 mm
Foot length		2000 mm
Foot median		5000 mm
Top width		170 mm
Foot irregularity		30 mm
Weight	1 kg	

G.5 SPINNAKER

G.5. MATERIALS

(a) The fibres shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

G.5.1 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The following are permitted: Stitching, glues, tapes, corner eyes, tape eyes, tell tales, sail shape indicator stripes, sail identification, sail-maker labels, sail sticker, **certification mark.**

G.5.4 DIMENSIONS

	minimum	maximum
Luff lengths		7000 mm
Foot length		5000 mm
Foot median		8600 mm
Difference between diagonals		50 mm
Half width		5600 mm
Weight	0.9 kg	

In the next pages I'll expose the testing of the chosen geometry extracted from the rules above with a CFD software but before show the results of the sails test I'll explain what a Computational Fluid Dynamic (CFD) software is. The aim of this test is not get in sail shape performance, it has no sense taking into account that if sail design is open and there are just some limits.

Computational Fluid Dynamics Test

Fluid flows are governed by partial differential equations which represent conservation laws for the mass, momentum, and energy.

Computational Fluid Dynamics (CFD) is the art of replacing such systems by a set of algebraic equations which can be solved using digital computers.

CFD provides a qualitative (and sometimes even quantitative) prediction of fluid flows by means of mathematical modeling, numerical methods and software tools. CFD enable to perform numerical experiments in a virtual flow laboratory.

Quantitative description of flow phenomena using measurements are for one quantity at a time, at a limited number of points and time instants, for a laboratory-scale model and for a limited range of problems and operating conditions.

On the contrary quantitative prediction of flow phenomena using CFD software are for all desired quantities, with high resolution in space and time, for the actual flow domain, for virtually any problem and realistic operating conditions.

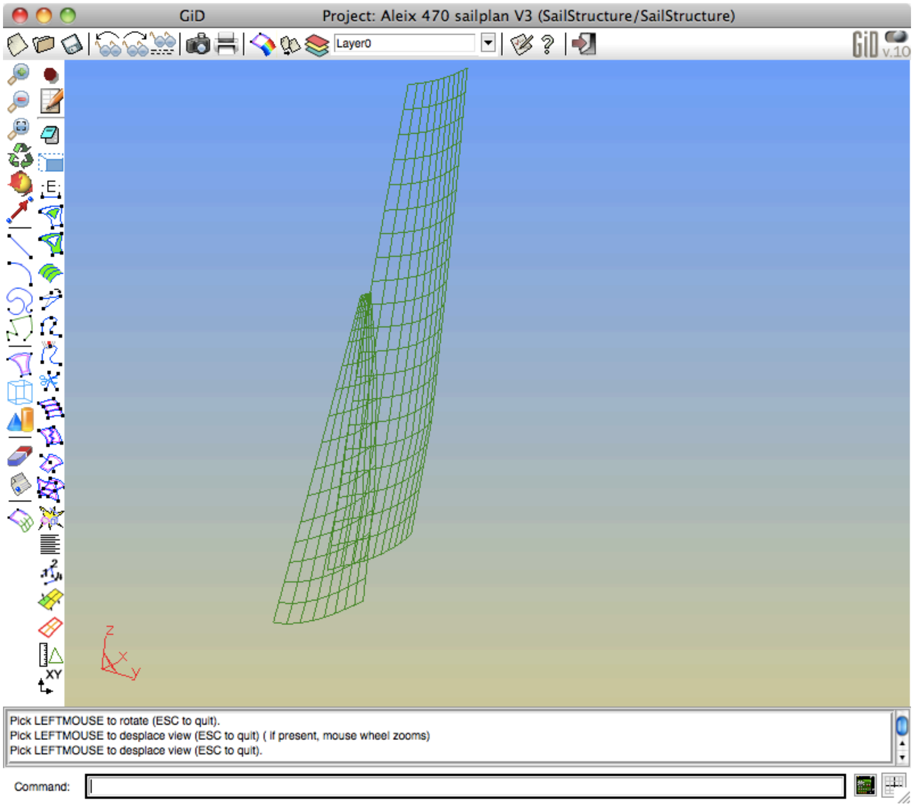
Regarding logistics we can appreciate experiments are more expensive, slower, can't be perform parallel and with just one purpose.

The problem is that CFD simulation are never 100% reliable because the input data may involve too much guessing or imprecision, the mathematical model of the problem at hand may be inadequate or the accuracy of the results is limited by the available computing power.

The quality of the simulation results depends on the mathematical model and underlying assumptions, the approximation type, stability of the numerical scheme, the mesh, the time step, the error indicator and others.

To draw conclusions about sails I used a CFD software developed by the researcher Inmaculada Ortigosa with GiD[13] as preprocess and post-process software and which consist in a vortex lattice method (VLM) CFD.

[13] GiD is a pre and post postprocessor for numerical simulations in science and engineering. Covering needs as geometrical modelling, mesh generation or analysis data.



13. Meshed sails in GID software window before execute the CFD. Own Source.

A vortex lattice method is a model of a continuous doublet sheet which permits the computation of separate pressures on each side of the surface. The method permits vortex shedding from the foot and leach of the sail and calculates the subsequent roll-up.

Yacht sails are thin lifting surfaces operating at moderate to high Reynolds numbers in a low-speed flow, so it is natural that they should be modeled as thin surfaces carrying vorticity (sheets of doublicity) in an incompressible, inviscid fluid; leading to the numerical model of a vortex mesh.

A common feature of most vortex lattice methods is to regard a system of line vortices as equivalent to the continuous distribution of doublicity, including equating the forces acting on the doublet sheet to the forces acting on the line vortices making up the mesh.

The sail surface carrying the continuous distribution of doublicity is discretized to be solved into a set of panels (not necessarily flat) each carrying a locally constant value of the doublicity that is identified as the actual value for the doublicity at some point in the panel.

The discretization has been done by discretizing the surface uniformly into equal rectangular panels and the collocation points have been placed at the geometric centre (or centroids) of each panel.

As a result the overall loads on a lifting surface are usually predicted with good accuracy.

The VLM is built on the theory of ideal flow. This method neglects all viscous effects. Turbulence, dissipation and boundary layers are not resolved at all.

Finally regarding when we compute the loads on the sail we have two options in this CFD. The first option is use the Katz & Plotkin method which just gets the lift of each panel, calculates the pressure from it and combines the pressures. The second option is the Fiddies method which calculates the pressure in both sides of the sails in a panel and then the sum of them. From these results we obtain the nodes, and the pressure difference across the sail (calculated from the doublicity solution) is integrated across each sail and resolved into lift and drag components.

Before showing the results of CFD test data I should explain the relevant entries in the CFD as well as the supposed conditions.

Both methods, and the CFD have been compared accurately by the researcher Inmaculada Ortigosa with experimental data and the results were good.

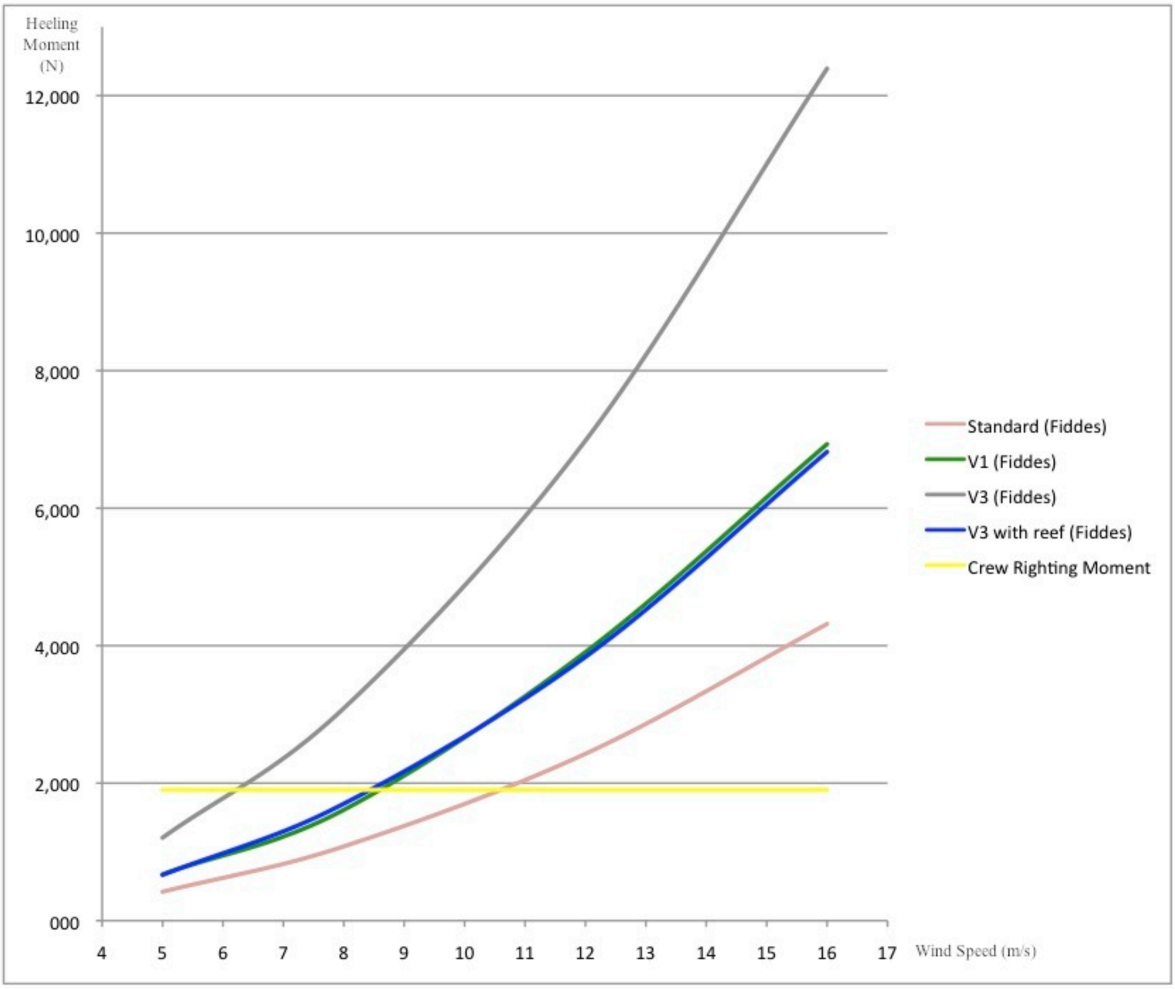
With this CFD software I have compared the sails in four wind conditions with a small entry angle, specifically 23 degrees. This angle is similar to an upwind angle, the most critical situation for the main and the jib. The four chosen wind conditions were 5 m/s, 8 m/s, 12 m/s and 16 m/s which represent broad wind conditions.

It's important to be conscious that these wind speeds are always apparent wind, are the speed at what wind entry in the sail.

From the CFD I have extracted a results chart[14] with the resultant forces in the sails in the aerodynamics centre of effort, the lift and drag coefficients and those coefficients in each sail.

Then I have calculated the heeling force which going to represent our limit. As we have explained we just can equal the heeling force with our weight until a wind speed point, from these point forward we must loose the sails to avoid be overpowered heeling the boat and losing boat speed.

These two line graphics represents the sails heeling moment upwind in compare with the crew maximum righting moment.



14. Upwind heeling sails moment coming from Fiddies CFD results and maximum crew righting moment. Own source.

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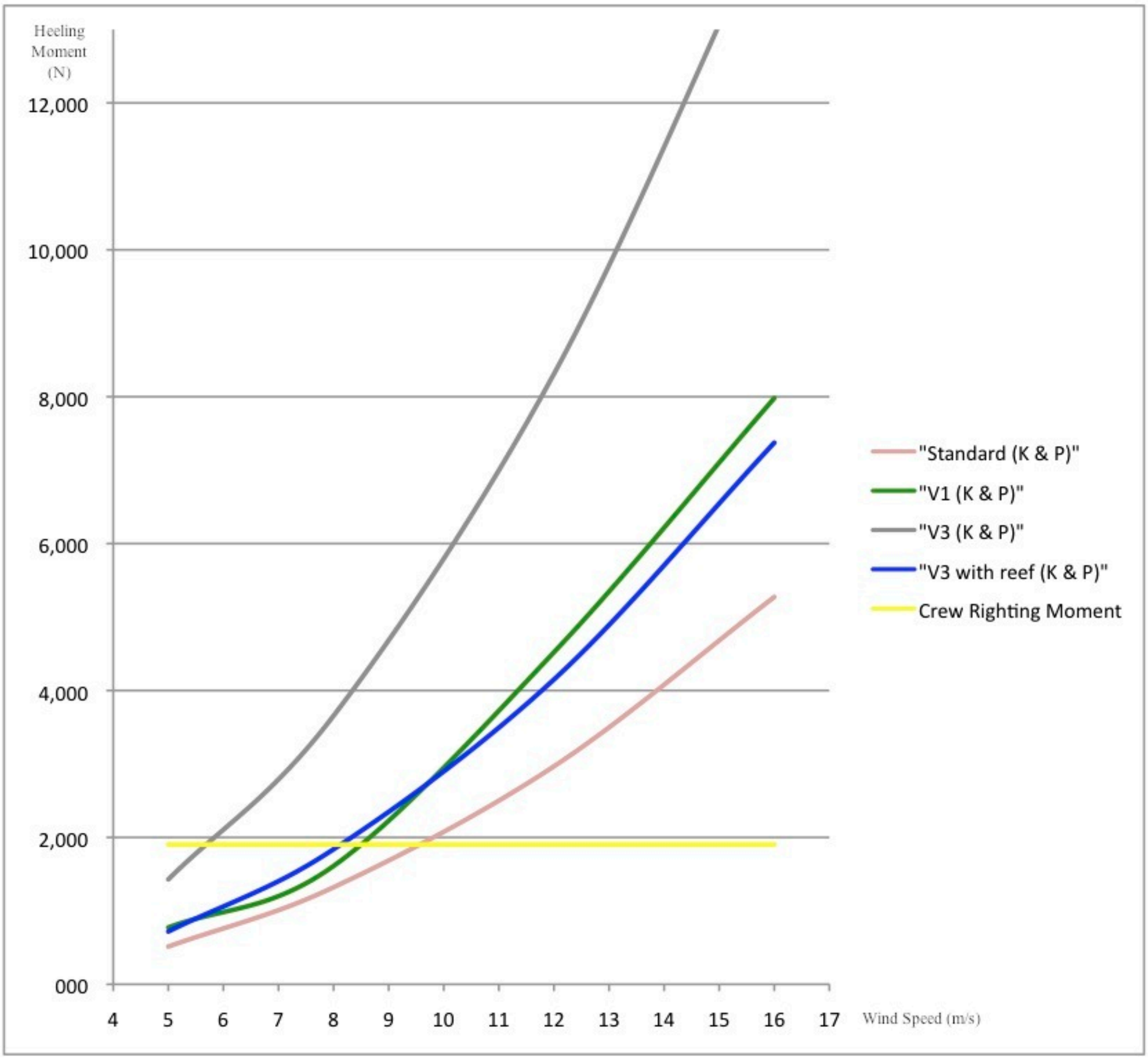
[14] You can find the complete chart in the Appendix 3



15. Upwind heeling sails moment coming from K & P CFD results and maximum crew righting moment. Own source.

As we can see the heeling moment has increase in all new sail versions as we could have predict because the increasing of sail area and the aspect ratio.

This means something else apart from heeling moment. If we consider these graphics plus the transversal force in the sail represented in the next page charts we can conclude that forces has increased considerably in V1 and has almost doubled in V3 version which means that speed in light must be increased, acceleration must be boost and the boat will plane earlier accomplishing some goals of this project.

Either, in the graphics and the charts we can see that by using a main reef in V3 we achieve the same performance on V1 for breeze.

Speed	Sailplan	Normal Sail Force (N)
5 m/s	Standard	143
	V1	201
	V3	297
	V3 with reef	210
8 m/s	Standard	368
	V1	481
	V3	760
	V3 with reef	538
12 m/s	Standard	827
	V1	1 166
	V3	1 718
	V3 with reef	1 213
16 m/s	Standard	1 470
	V1	2 069
	V3	3 050
	V3 with reef	2 157

16. Part of the Fiddies CFD results. Own Source.

Speed	Sailplan	Normal Sail Force (N)
5 m/s	Standard	174,92
	V1	230,92
	V3	351,51
	V3 with reef	227,14
8 m/s	Standard	449,94
	V1	480,80
	V3	899,87
	V3 with reef	581,48
12 m/s	Standard	1010,73
	V1	1349,22
	V3	2044,98
	V3 with reef	2332,34
16 m/s	Standard	1796,07
	V1	2382,06
	V3	3619,64
	V3 with reef	2332,34

17. Part of the K & P CFD results. Own Source.

Dominance Ratios

Apart from the CFD testing direct results we can evaluate the new sails in other way, with dominance ratios.

The dominance ratios are dimensionless values, sometimes express as percentage, which establish a relation between relevant aspects allowing us to compare different boats and so obtain conclusions.

The performance level of planning dinghies is overwhelmingly governed by the three dominance ratios.

The first one is the Sail Area Downwind / Wetted Area[15] which governs light air performance. In light winds the most part of the hull resistance is friction resistance so if we increase the sail area, that means increase power, or reduce the wetted area, that means less friction, the boat will increase the speed. As we can see in the chart below I have improved this ratio in V1 sailplan and almost double in V3 version. These numbers are valid just when the boat haven't began to plan because of the considered wetted surface, and that's why I haven't write it for V3 with reef too.

Standard	V1	V3
6,76	7,82	13,14

18. Sail Area Downwind / Wetted Area 470 values. Own source.

Once the boat is planning the wetted surface change with the speed reducing to unbelievable areas, so don't has sense to take in account an area because depends on the speed in each moment and what I did is consider the second ratio, Sail Area Downwind / Total Weight. In this case I could compare with other boats with better performance in current models to see how much have the new models improved. Results are given in percentage.

Standard	V1	V3	V3 with reef	505	49er	18ft
9,70%	11,21%	18,84%	16,49%	14,29%	22,80%	24,86%

19. Sail Area Downwind / Total Weight 470 and other boats values. Own Source.

[15] To get this wet surface I modeled the boat in Maxsurf. Maxsurf is a modelling tool specialized in boat design which works with NURB surfaces. Maxsurf is the starting point for the full hull definition and a tool to determine the possible behavior of the boat in the water. You can find a picture of the model in the Appendix-4

As you can see the new V1 hasn't changed the boat performance so much because the sail area hasn't increased a lot. The spinnaker, which makes the big difference in this case, isn't much larger. On the other hand the V3 has doubled the current model, outdoing the 505[16] and getting closer a 49er[17] or even a 18ft[18], the extremest monohull dinghy. This percentages ensures speed and spectacularity sailing downwind. Both improvements were goals to achieve.

Both ratios are high benefit by the spinnaker area increased, making it clear how important is this "small" change.

The other two ratios are upwind sailing ratios. In light wind we apply the Sail Area Upwind / Wetted Area like downwind, with significance increasing.

Standard	V1	V3	V3 with reef
3,34	4,08	5,81	4,17

20. Sail Area Upwind / Wetted Area 470 values. Own source.

And the Sail Area Displacement ratio that considers the weight and the sail area and represents the power of the boat. This ratio has boosted with new version and V3 outdo even the 49er. I can say that the boat acceleration, the energy, will be incredible. And in the case of V3 with reef the power is quite maintained, guaranteeing the performance in breeze.

Standard	V1	V3	V3 with reef	505	49er	18ft
4,93	6,01	8,56	6,14	5,23	8,06	9,66

21. Sail Area Displacement ratio of 470 and other boats. Own source.

Others ratios exists but I considered that the important to extract conclusions about this issue were the ratios explained above.

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[16] The 505 is a one-design high-performance two-person planing dinghy, with spinnaker designed by John Westell.

17 The 49er is the Olympic skiff, two handled with two trapezes and asymmetric spinnaker.

18 The 18ft are considered the Formula 1 of the water, are 3 crewed and is an open rules class which means that many changes are allowed and the boat it's constantly being developed getting it to the boat design top.

8. The Mast

Once I have developed the new sails. V3 sails need a new mast where fit them. In this chapter I'm going to define how a mast should be and at the end I'll dimension the mast for these sails.

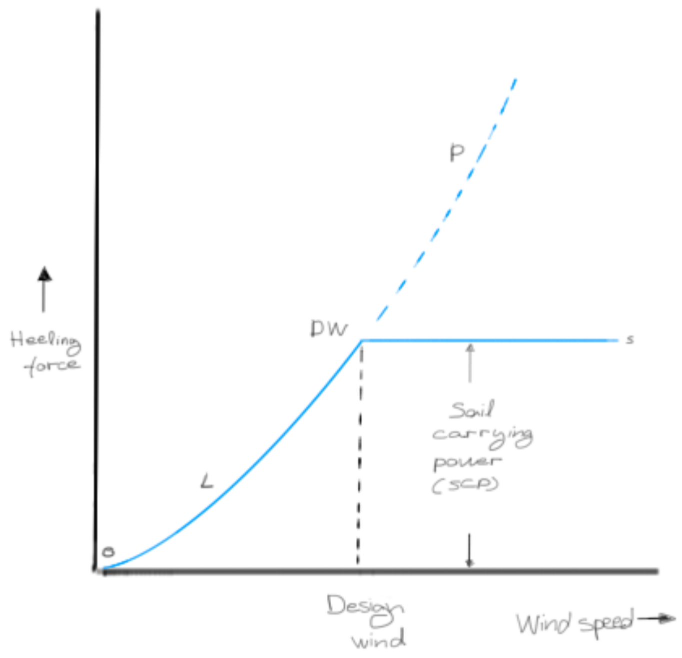
When we're sailing in light winds we need a fuller main, we need power. When the wind increases a bit we need power yet, but there's a point[19] and thereafter from which we don't want much power so we want to flatten the sail. To achieve this in a Bermudan rig we have two options; changing the sail depending on wind intensity and using a stiff mast or by flexing the mast to flatten the sail. Clearly, if it's possible, is easier to trim the mast than change the sail. And if you trim the mast you could adapted the sail better in all wind conditions, it's like have "infinite" sails. That mast, in light air and in progressively stronger breezes must be stiff until the point when the sideways force developed by the sails will balance the crew who are hiked and trapezed to extreme. Forward this point the mast must yield to shed power. So we are going to design this optimum mast as a flexible mast.

A flexible mast has another benefit. Always, we had thought that a boat with a higher forestays and a larger jib would have beat the other, but why was that sailboats with low forestays and smaller jibs usually beat ones with higher forestays and larger jibs?

The low forestay allows the masthead of the flexible mast to yield backwards as the tension in the leech increases in stronger wind: these both flattens the upper mainsail and allows the leech to fall to leeward. If the forestay attachment point is low enough, the increasing backwards force at the masthead tightens the forestay sufficiently to reduce its sag, and so flattens the headsail as well. Then a mast with a low forestay is good to allow the mast flex.

Because of the two reasons above are important to have well defined the design wind. It's the turning point where we pass from be interested in power to need to shed power. It's the point where the mast should begin to flex over the forestay by its own and we should yield the mast to flatten the main.

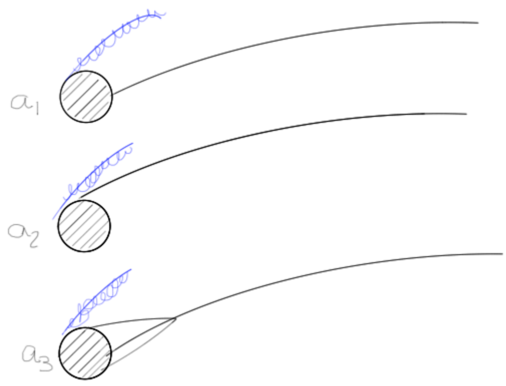
[19] This point is called the design wind point, thereafter we can't make enough righting moment so we must loose the sails.



O - L - DW - P = Maximum heeling force which can be developed by sail.
SCP (Sail carrying power) = Righting moment / arm
Dw = Design wind
O - L - DW = Wind speed range in which crew look for power.
DW - S = Stronger wind speed range in which crew must shed power.

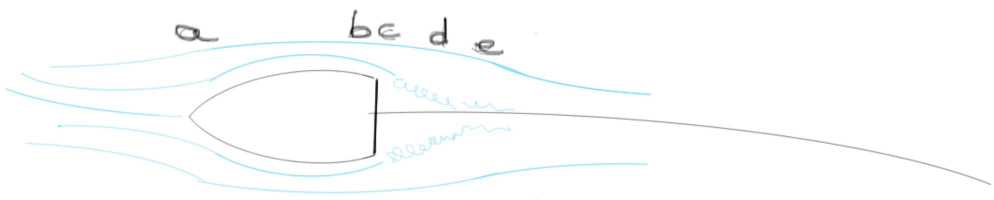
22. Elements of the design wind concept. Own source.

Other aspect of mast design is the influence of the mast in the entry area of the sail. When we thought about sails we just focus in the sail itself and we didn't consider the turbulence would be created when we place a mast almost hundred times thicker between the sail and the entry flow. Some things have been tried to clean up the turbulence in round mast, but they failed. Turn the mast with the sail was good for the entry sail shape but the turbulence persevered. And close from the back part of the mast until the sail wasn't a solution neither.



23. Conventional round mast. Aerodynamics are inefficient. a_2 and a_3 are not better than a_1. Own source.

After these failed attempts to clean up the turbulence in round masts, we should consider try to use another mast shape to clean up them. So the best way to avoid the turbulence is using a wing form. And with wing-mast we achieve have the turbulent flow re-attached to the sail.



a Flow accelerates over shaped wing-mast.
b is turned inwards.
c and is separated from the knife edge.
d The free shear layer becomes turbulent.
e and immediately reattaches, turbulent, to the sail.

24. Mechanism of trip turbulator on modern wing-mast. Own Source.

We already have a mast that yield as much is necessary, only when is necessary and we have a mast that doesn't disturbs the entry flow in the sail but what's about the mast stability?

We can increase overall mast stability by increasing the number of spreaders and by bringing the mast down to the keel. Let's see the advantages and disadvantages of them.

If we increase the number of spreaders we can use a thinner mast which gives better mainsail efficiency. Smaller outer dimensions or wall thickness giving a lighter mast. And smaller foresail sheet angles are possible. On the contrary the mast will be more difficult to trim and is higher cost.

If we bringing the mast through deck we can use a thinner mast, smaller outer dimensions or wall thickness which give a lighter mast and like increasing number of spreaders smaller foresail sheet angles are possible. On the contrary we have more difficult to trim, high horizontal forces in deck level and risk of heat and water leakage.

Another thing we must do is choose between wire, rod or textile rigging and we should consider: The breaking strength which normally, a rod is 20% stronger than wire of the same diameter and textile is the strongest. The fatigue which means the number of loads that can be applied before the wire or rod breaks, wire is more sensitive to fatigue, but rod is sensitive to surface damage which can lead fatigue-cracking the textile it's the worst in this case. The resistance to corrosion is the same for both wire and rod and there's no corrosion with textile rigging. The elongation of the rod is lower than wire and the elongation of the textile in many cases is lower than the two others. The weight is clearly lower for the textile. And the last comparison factor is the price which wire is the cheapest then rod that cost about 50%-100% more and then the most expensive, the textile.

Finally we should decide the material of the mast. The current mast is made of aluminum but I think that a carbon mast will be best in weight, fatigue resistance and so durability.

Concluding I would choose a soft carbon mast with wing shape, many spreaders, through the deck, with a textile rigging and lower forestay as and ideal mast. But considering the initials ideas I'll just do a soft carbon mast with round shape, two aluminium spreaders, through the deck, with wire rigging and lower forestay. Thereby I will preserve the idea of reachable boat with more durability. I also divide the mast into 3 parts to facilitate the shipping, allow to regulate the lower spreaders while sailing and not limiting the yielding of the mast.

To dimension the new rig I could follow the steps from Larsson's book[20] or other sail boat methodology, but there's a problem. Those methods are thought for keel boats and "heavy" boats. The 470 is a dinghy and in this case the mast bend more than in bigger boats, and is under different amount of stress.

So because of that the best way for choose the new mast shape is use the experience from other similar boats and think about how are the force going to act.

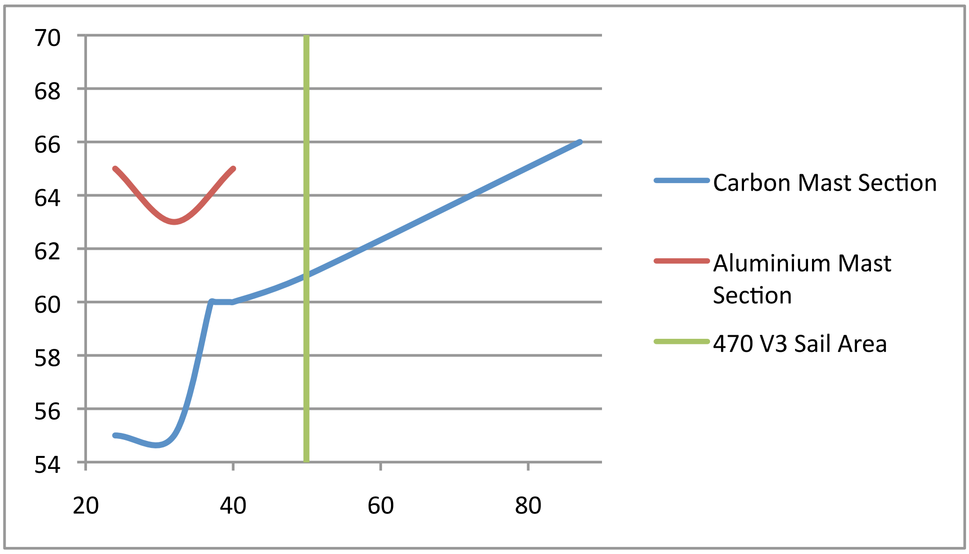
After define the sail-plan and jib halyard height what I should choose first is the height I must situated the spreaders. The lower one's are on a proportional height with the current

[20] Principles of Yacht Design, Lars Larsson and Rolf E. Eliasson.

mast and the top spreaders are over the jib halyard at the same distance that the halyard is from the lower spreaders. The shroud fits on the mast at the top of the mast, just over the spinnaker halyard. And there is a diagonal shroud from the lower spreader to just over the jib halyard.

The mast is divided in the points where is going to bend less to avoid problems. The easiest way to join the parts is by making the one part entering in the other and the other have an external ring which stops enter more than 200 mm in the other. And to avoid any rotation between the parts I'm going to use the main sail groove or track.

And finally to choose the mast section what I did was compare with other similar boats which used aluminium masts years ago and who have change to a carbon mast and compare with similar boats that use Carbon Mast and has as sails area as the new 470 V3 version. So from the graph below, where're data from boats like 18ft, 14ft, 505, 59er, International Canoe, RS800, Merlin Rocket or Flying Dutchman; and some other data not considered in the graph like laminated thickness or other boats experience I decided to use from 60 to 62 mm section for the low and the middle mast parts and from 55 to 58 mm at the top part.



25. Mast Section for Sail Area in light mono-hulls. Own source.

In the next pages you can see the new 470 rig rules[21]. Remember that the new rules as the older one's are in the Appendix 1.

[21] [21] The pictures include in the rules come from the old rules, defined by the 470 class.

V3 Rig Rules

C.11 RIG

C.11.1 LIMITATIONS

(a) Only one mast, boom and spinnaker pole shall be used during an event except when an item has been lost or damaged beyond repair.

C.11.2 DEFINITIONS

(a) MAST DATUM POINT

The **mast datum point** (MDP) is the **heel point**. Unless indicated otherwise, all measurements are from the MDP-

C.11.3 MANUFACTURER

(a) **Spar** manufacturer is optional.

C.12 MAST

C.12.1 MATERIALS

(a) The **spar** shall be of carbon. Titanium or carbon are not allowed for fittings. Differences in laminated thickness are not allowed in a mast part.

C.12.2 CONSTRUCTION

(a) The **spar** shall include a fixed sail groove or track, which shall not be integral with the **spar.** The **spar** shall be round.

(b) The **spar** is composed of 3 parts of length defined in C.12.4

C.12.3 FITTINGS

(a) MANDATORY

(1) A gooseneck.

(2) Kicking strap attachment.

(3) Spinnaker pole fitting.

(4) Spinnaker pole downhaul blocks and/or sheave boxes with attachment.

(5) Spinnaker pole lift blocks and/or sheave boxes with attachment.

(6) Four fixed or adjustable metal **spreaders** with optional attachment systems which may include local reinforcement according to C.12.4

(7) Headsail halyard block(s) and or sheave box(es).

(8) Attachments for shrouds, forestay and trapezes.

(9) Spinnaker halyard blocks and/or sheave boxes.

(10) A sheave or sheave box and a rack lock or cleat for the mainsail halyard.

(11) A device to ensure compliance with ERS B.9.1 (a) if the mainsail halyard system itself does not do so.

(12) Permanently painted/taped **limit marks.**

(b) OPTIONAL

(1) A heel fitting.

(2) A fitting for centreboard hoist blocks.

(3) Mainsail halyard blocks and/or sheave boxes.

(4) Headsail halyard cleat.

(5) Fitting(s) for cunningham adjustment.

(6) Reinforcement at mast partner according to C.12.4.

(7) A removable timing device.

(8) Attachment fittings for removable compass.

(9) A fitting to attach mainsail **tack** to **spar.**

(10) Devices attached to the **spreaders** to prevent the spinnaker halyard form getting tangled.

(11) A masthead fittings which may include a mainsail halyard sheave.

(12) One mechanical wind indicator.

(13) Fittings for the lower spreader regulation system.

C.12.4 DIMENSIONS

	minimum	maximum
Mast spar permanent bend **fore-and-aft**		40 mm
Mast spar section between MDP and 5950 mm	55 mm	58 mm
Mast spar section between 5950 mm and top	60 mm	62 mm
Mast limit mark width	10 mm	
Lower point height		1055 mm
Upper point to the **lower point**		7750 mm
Forestay height	6480 mm	6500 mm
Trapeze height	8605 mm	8655 mm
Shroud height	8555 mm	8605 mm
Diagonal **shroud height**	6520 mm	6570 mm
Lower part lenght	2170 mm	2175 mm
Middle part lenght	3770 mm	3775 mm
Top part lenght	2880 mm	2885 mm
Overall lenght	8800 mm	8805 mm
Overlap between parts	250 mm	
Spinnaker pole fitting:		
height	1240 mm	1260 mm
projection		40 mm
Spinnaker hoist height		8505 mm
Lower spreader height	4200 mm	4300 mm
Higher spreader height	7400 mm	7500 mm
Jib halyard height	6380 mm	6420 mm
Distance between the aft face of the mast and the gooseneck pivot		35 mm

C.12.5 WEIGHTS

The weight of the **mast** includes rigging specified under C.15.2; C.15.3 (a) (1); C.16.2 (a), fittings specified under C.12.3 and permanently fastened compass bracket if applicable, but without wind indicator, compass and/or timing device:

	minimum	maximum
Mast weight	6 kg	
Mast corrector weights		0.2 Kg

Corrector weights shall be permanently fastened so that no part of the corrector is more than 200 mm from the **upper point.**

C.12.6 CONDITIONS FOR USE

(a) USE

(1) The fore and aft bend of the mast **spar** may be controlled at the mast partner by one of the following devices:

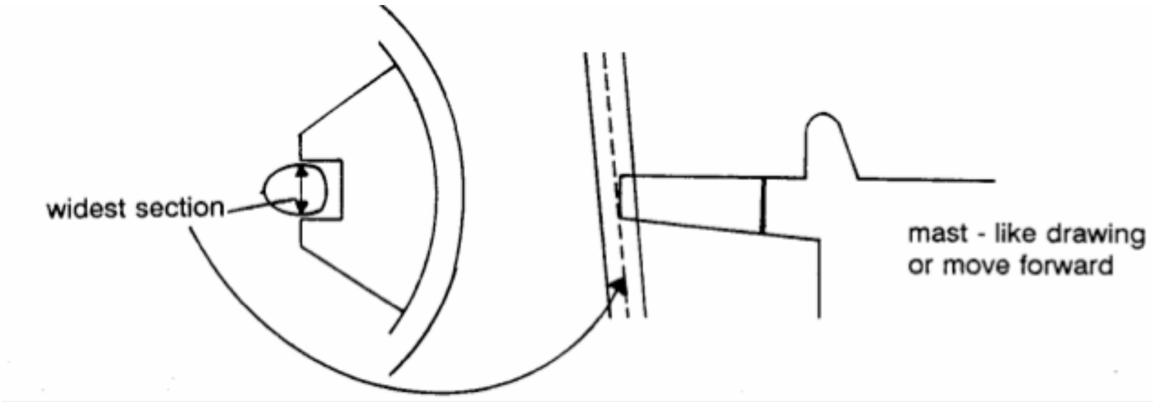
(i) Chocks between the mast **spar** and the mast partner (forward of the mast).

(ii) Optional systems of ropes or wires which may include attachments, blocks, levers, grips and cleats, all located on top of the mast partner.

(2) The sideways play between the mast **spar** and the mast partner may be controlled by strips of any material permanently fastened to the mast partner.

(3) The mast heel position shall not be adjusted while racing.

(4) The forestay under tension shall be entirely in metal and shall prevent the mast from disengaging from the mast partners. To meet this requirement the widest section of the mast shall be within the mast partners when the mast rakes under its own weight and the forestay comes under tension, as Figure “Mast Rake with Tensioned Forestay” shows:



Mast Rake with Tensioned Forestay

(5) Adjustable spreaders if used; the down spreaders may be remotely controlled, and may be adjusted when racing and top spreaders shall not be remotely controlled, and shall not be adjusted when racing.

C.13 BOOM

C.13.1 MATERIALS

(a) The boom **spar** shall be of aluminium alloy.

C.13.2 CONSTRUCCION

(a) The **boom** shall include a fixed aluminium sail groove or track which may or may not be integral with the **spar**.

C.13.3 FITTINGS

(a) MANDATORY

(1) A gooseneck attachment.

(2) A kicking strap fitting.

(3) Main sheet block(s) with attachment fittings(s) for the blocks and/or mainsheet which may be adjustable.

(4) Mainsail **clew** outhaul attachment or adjustment system.

(5) A stopper to ensure compliance with C.17.4.(b).(4).

(6) Permanently painted / taped **limit mark**.

(b) OPTIONAL

(1) A fitting to attach mainsail **tack**.

(2) An aft **spar** end fitting.

(3) The **spar** may be protected in the area where it touches the shrouds by pieces of any material, with maximum length / height / thickness = 100/50/5 mm.

C.13.4 DIMENSIONS

	minimum	maximum
Boom spar deflection when laded with 80Kg at a point midway between points 100 mm from each end and with the groove uppermost:		
vertical		50 mm
Boom spar cross section		
vertical	54 mm	72 mm
transverse	38 mm	
Radius of convex edges excluding those of external or internal tracks or grooves	5 mm	
Except within 150 mm from each **spar** end, the boom section shall be constant.		
Limit mark width	10 mm	
Outer point distance		2650 mm

C.14 SPINNAKER POLE

C.14.1 MATERIALS

(a) The **spar** shall be of aluminium alloy.

C.14.2 FITTINGS

(a) A hook at each end.

(b) Fittings approximately at the mid-point for attachment for lift/downhaul.

(c) A fixed line between the fittings described in C.14.2 (a), which may incorporate knots, toggles or short tubes for easier handling.

C.14.3 DIMENSIONS

	maximum
Spinnaker pole length	2200 mm

C.14.4 CONDITIONS FOR USE

(a) Only one spinnaker pole may be carried aboard.

(b) The spinnaker pole shall float in the water at least 15min.

C.15 STANDING RIGGING

C.15.1 MATERIALS

(a) The standing rigging shall be of stainless steel wire rope. Rod rigging is prohibited.

C.15.2 CONSTRUCTION

(a) MANDATORY

(1) A forestay of a diameter not less than 2.3 mm.

(2) Two shrouds of a diameter not less than 2.3 mm

(3) The material of the trapeze line is optional, if wire is used it shall have a diameter not less than 2.3 mm. Each trapeze wire shall be provided with handholds, rings and adjustment. Self-tacking trapeze systems are not allowed.

(b) OPTIONAL

(1) Elastic cords on the trapeze wires approximately at the height of the spreaders.

(2) Shock - cord may be fitted between the forestay and the stem head fitting to maintain tension in the forestay.

C.15.3 FITTINGS

(a) Forestay attachment fittings.

(b) Each shroud shall be attached to the shroud plate by means of plates having row of adjustment holes. No other arrangement of shroud adjustment is permitted.

C.15.4 CONDITIONS FOR USE

(a) The effective length of the shrouds shall not be adjusted when racing.

C.16 RUNNING RIGGING

C.16.1 MATERIALS

(a) Materials are optional except that Titanium is prohibited.

C.16.2 PARTS

(a) MANDATORY

(1) Mainsail halyard.

(2) Headsail halyard.

(3) Spinnaker halyard.

(4) Spinnaker pole lift and downhaul.

(b) OPTIONAL

(1) Mainsail Cunningham line.

(2) Mainsail outhaul.

(3) Mainsail reef system.

C.16.3 FITTINGS

(a) OPTIONAL

(1) One block or eye in each head sail Barber hauler to run on spinnaker sheet or guy.

C.16.4 CONDITIONS FOR USE

(1) **Sails** and sheets may be move directly by hand without the use of a block.

Rig conclusions

Apart from the conclusions made before the rules I can say that applying the rules above we achieve completely freedom in the mast trim.

By don't narrowing the mast bend allow to sail a wide rank of weight people. Light crews can get advantage from soft masts while heavy crew can get advantage from the power of a stiff mast. The remotely controlled lower spreaders increase the technical level of the boat and make it more efficient with breeze.

The reef system makes the boat efficient upwind with breeze and incorporates another factor which you should think while racing.

The buoyancy of the spinnaker pole avoids the infinite number of them that are in the deep sea because of a capsize.

I get the proposed goals in this part, either.

9. The Hull

As I've said at the beginning, I'm not going to change the water lines because I want maintain the spirit of the boat but I'll change deck shape, the inside structure and I'll use longer life materials and better construction methods.

All these changes will affect straightly to the Dynamic nature and the life of the boat reducing costs mid and long term and achieving better performance in handling, acceleration and speed.

Additionally I've placed small boxes to improve media either.

To analyze each change I can divide the hull changes in these three parts:

- Deck Shapes.
- Structure and production process.
- Materials.

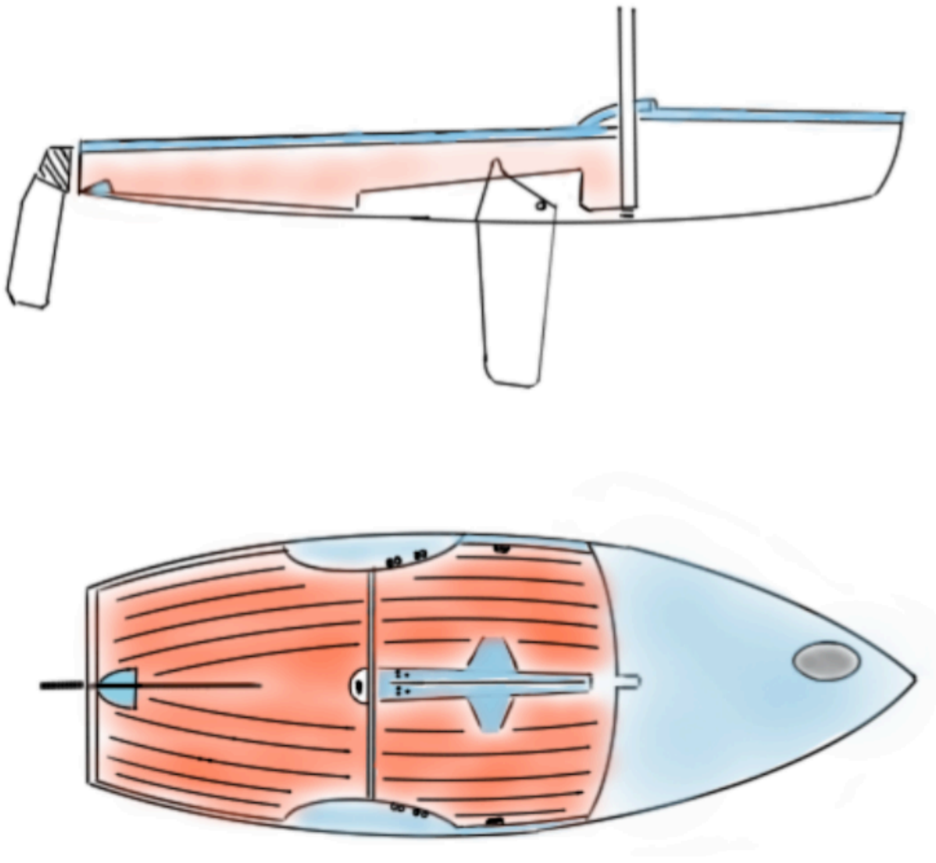
During the next pages we'll see them.

Deck Shapes

The 470 deck is quite optimized: it's well distributed to host all the systems, it has a closed bow which avoid water from entering in the boat and allows the helm to be seat comfortable.

On the other hand the water that enters in the boat is not easy to bail because the bow cockpit area is lower than the aft when sailing, the crew has a small and uncomfortable area in the cockpit so in light winds when the crew isn't on the trapeze and she is changing her position the side tank complicates the movements, spinnaker backs make impossible for the crew to move forward and sometimes causes problems with the systems circulating in the bow, and place a camera is a challenge which you ever will be worried of what could happen to it.

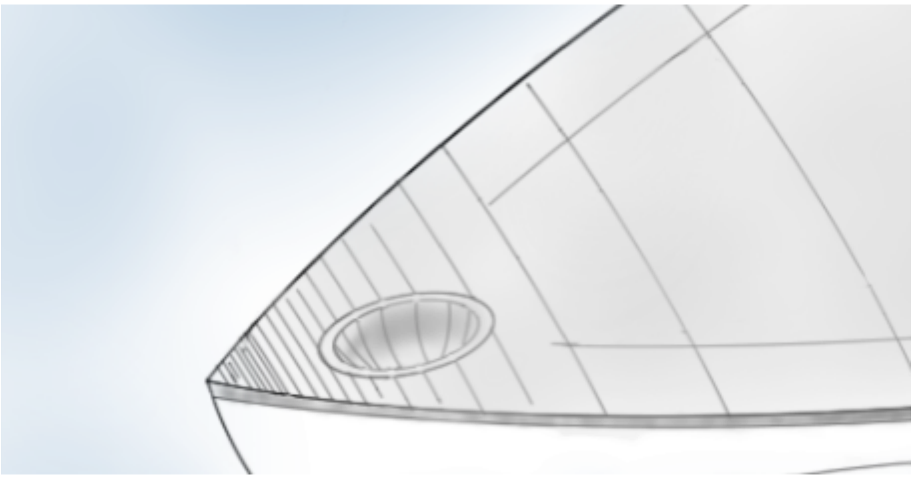
Based in these reflections, comparing with other boats and from my personal experience I decided to change the deck in the way you see in the sketch below.



26. Top and side view of the new 470 deck (The draw it's not scale). Own source.

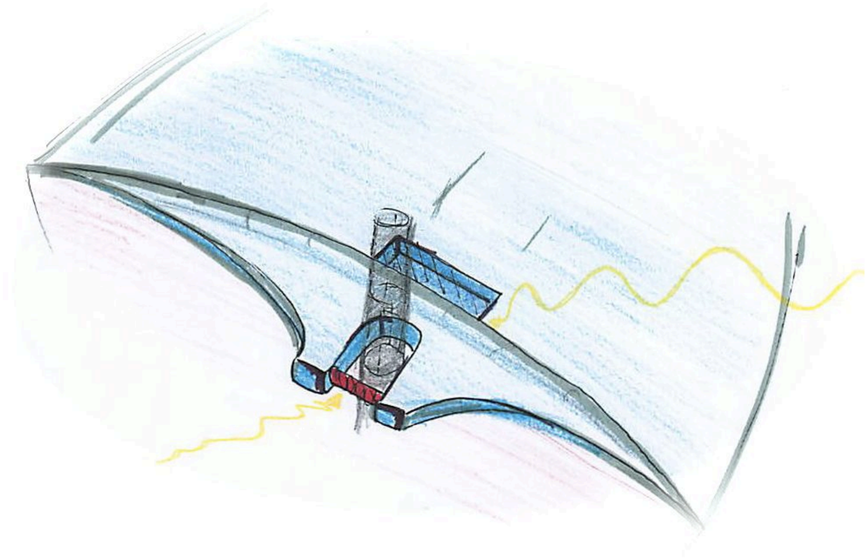
The side tanks have been reduced just keeping the area used by the helm to seat while sail. By this, the cockpit area has increased and the weight has been reduced drastically especially in the aft which is very important to plane downwind. So we have won comfort for the crew, a better position for the jib travelers because they are far outside, the side tank will act as a reinforcement for the main traveller too, and we have decreased the costs due to the mold that will be more simple.

The bow hole replaces the two spinnaker bags. This hole will contain an impermeable cloth tube for the spinnaker with and end in the cockpit that with a downhaul to pick the spinnaker will reduce the time of the spinnaker dropping, giving dynamism in mark rounds and getting cockpit space.



27. Detail of the dropping spinnaker hole. Own source

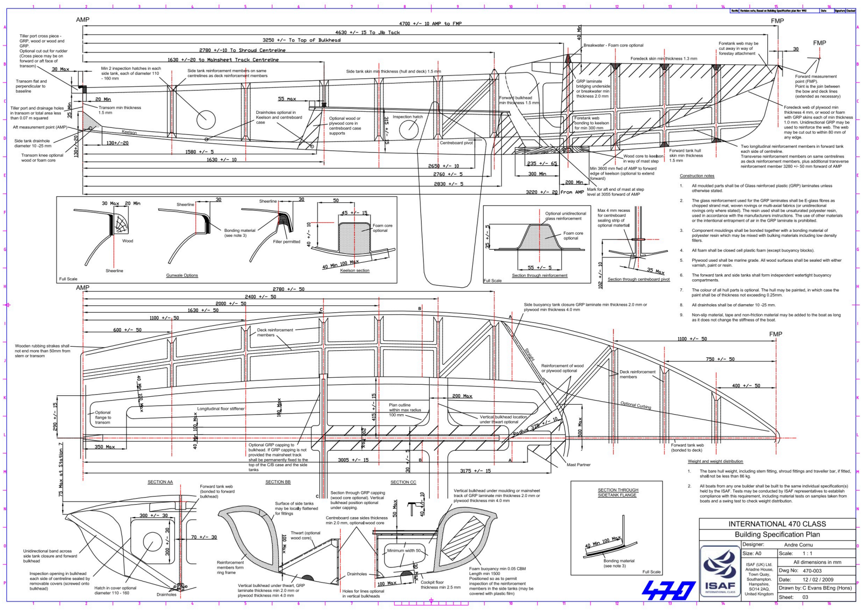
In the aft we find a small box thought to host a camera which record all the crew movements from inside during the race or while sailing. There are a bar next to the mast as support for another camera and another small box in the bow to place a GPS and other electronic gadgets that will boost the media of the boat.



28. Detail of the aft mast and bow to place electronic gadgets. Own source

Finally the last significant change is the cockpit floor. In the current model de cockpit floor is in a lower plan in the bow in relation with the aft so that makes that all the water that enter in the boat until a certain level stay in the boat unless we bail it. So we need a bailer or a sponge to bail. By leveling the cockpit floor we avoid this and it’s not necessary to install bailers which are a problematic part of the boat currently.

The structure and the production process



29. 470 Building specification plan. Source: ISAF

This is the current structure of a 470[22]. It has many transverse reinforcements and few longitudinal reinforcements and that's not the best. Let's see it.

A boat as any engineering structure is under stress originated by different inside and outside reasons which can be divided in structural stress and local stress.

Regarding the longitudinal structural stress we can see that the boat act as a beam with his weight and the crew as a load and thrust produced by the water displaced under the Archimedes principle. This situation is balanced globally but each part of the hull may not be balanced so internal stress appears. The beam will try to be bent by blending moments and shear.

If we consider that the boat is not just floating. If the boat is sailing we must count the waves presence. When we are sailing with waves, we must consider two critical positions: If the mid section of the boat is at the top of the wave or between two waves.

When the mid section is at the top of the wave is called hogging and the thrust will increase in the mid section and decrease in the ends producing tensions on the deck and compressions at the bottom. And when the mid section is between two waves is called

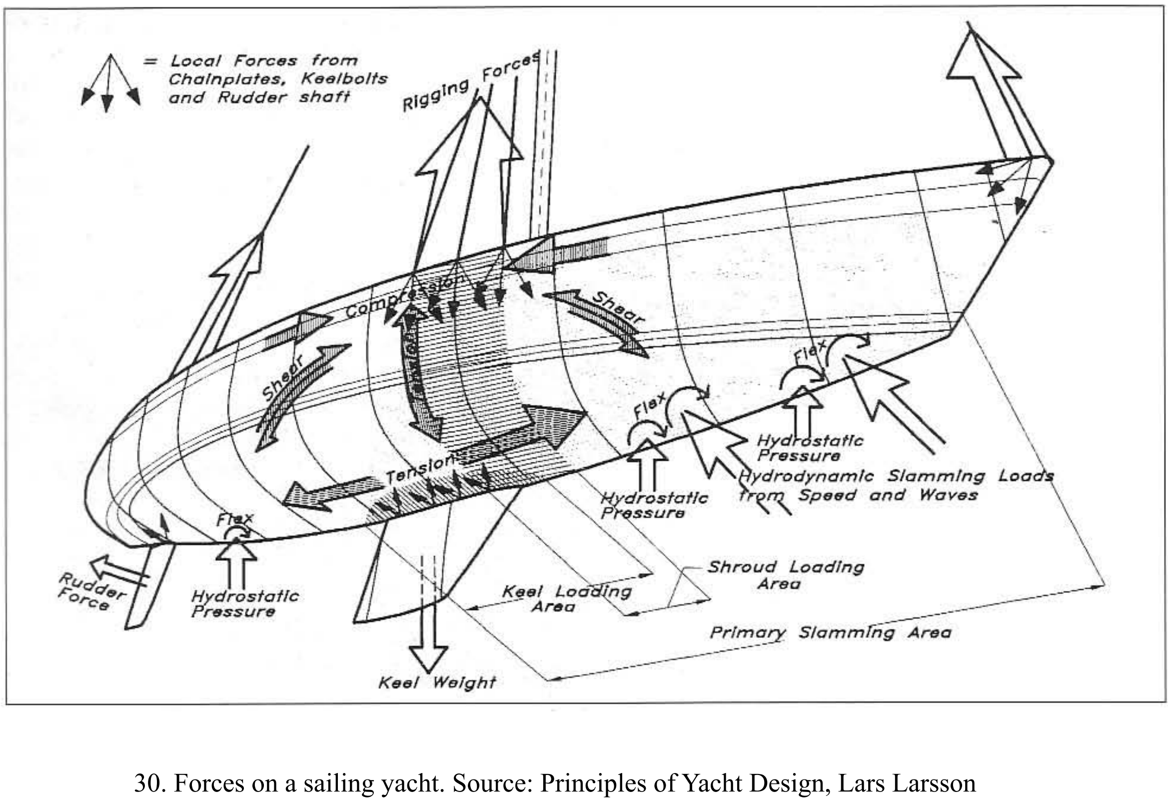
[22] You can find the plan full page in the Appendix 2.

sagging and the thrust will decrease in the mid section and increase in the ends producing compressions on the deck and tensions at the bottom. In a sailing boat the sheer is more critical than grief because we should add the load of the mast and the tension of the stay in the bow.

The transversal structural stress comes from the hydrostatic pressure in the wet surface and from the cross deformation caused by a turning of the boat.

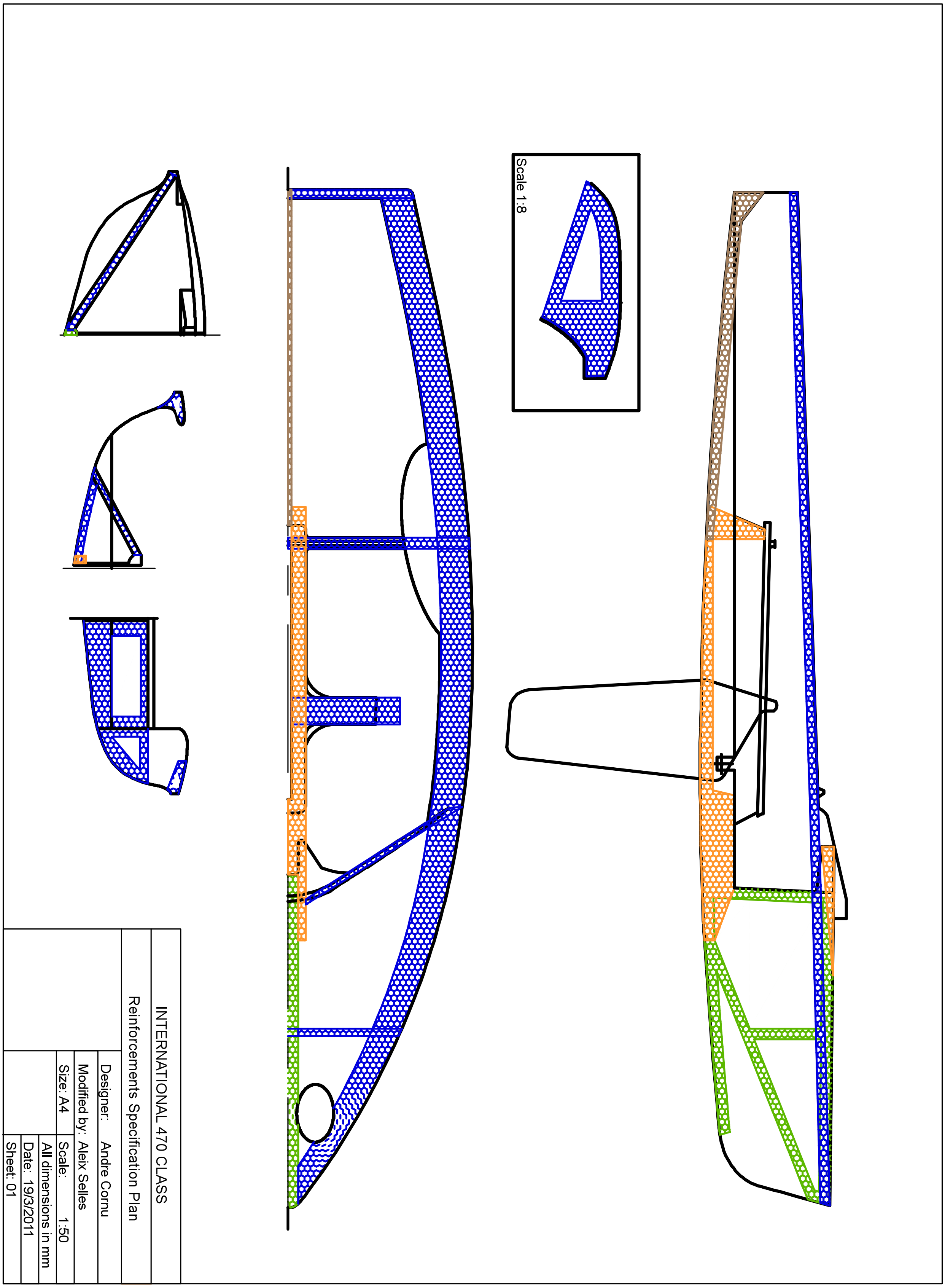
About local stress we find that it’s divided in: internal concentrate loads caused by the centerboard, rudder or the weight of the crew at specific place; the water hitting on the boat; and all the weights of a boat that acquire an acceleration sailing.

The next figure shows all loads and stresses of a sailing yacht, the 470 is under these loads either except the backstay load. Because of the size of a 470 the most important loads and stress are the slamming loads in all the bottom of the hull (when the boat plan is almost outside of the water), the board and rudder transversal or longitudinal loads and the rigging forces. Basically we must consider these forces when create the reinforcements and the hull.



30. Forces on a sailing yacht. Source: Principles of Yacht Design, Lars Larsson

So considering the stresses and which are notorious I defined this preliminary building plan with the aim of distributing the reinforcements.



It seems that I'm just changing some reinforcements for others.

But the current boat as you could see have more than 30 reinforcements and after laminated the bottom you must glue one by one all of them. Moreover you must glue the deck very well because of it will depend the performance and durability of the boat.

31. 470 under production. Source: Composites technology magazine

And what I did is made easy and with more warranties the building process, so with this structure the production is going to be cheaper because you will need less time, less precision in the production and you will get best results. The idea consist in laminate and prepare the reinforcements, then mount the reinforcements in one block and make the infusion of the hull making bottom and structure one piece and achieving maximum stiffness. Finally we glue the cover or deck and the boat will be finished.

I decided to make the lamination of the material by infusion because is a process with great results, easy to perform and affordable.

As main advantages that differentiate it from hand lay I can cite:

· Laminated parts are obtained with good mechanical properties. The quality is less dependent on operator.

· The volatile organic compound emissions to the work environment are greatly reduced.

· You can convert manual lamination molds.

· The labor required is lower.

· Secondary connections are reduced.

· There is a significant raw material savings and waste reduction.

At this point I couldn't define the laminated thickness in each area and which will be the total weight of the bare hull but I can foretell that using this structure and the materials described in next pages the weight will have been reduced drastically.

The materials:

As I've said in the beginning pages the 470 hull is build with 1960s materials. In those time the composites were expanding in naval sector, especially the glass reinforced fiberglass[23]. So the 470 was a modern built boat. In fact was more modern than if you make a boat of carbon fiber now, because carbon has been used more than 20 years by now.

Nowadays the fiberglass and the polyester resin are not a modern material or composite, they are the cheapest composite materials and at the same time are the worst in performance and durability.

In next paragraphs you will find different kind of fiber and resin to have brief knowledge of the most common and abstract a reasonable conclusion of it.

As I've said the cheapest and most extended fiber is fiberglass. Is mostly formed of silica and have these properties:

- Excellent mechanical resistance.
- Moisture resistance.
- Resistance to chemical attack.
- Low elongation.
- Excellent adhesion to the parent.

The carbon fiber use to form composites with epoxy achieving a light material with a high resistance and elasticity. It has these properties:

- High strength and stiffness.
- High resistance to vibration.
- Good resistance to fatigue.
- It is not affected by contact with seawater.

As main drawback we can mention its high cost.

The other most common fiber is the kevlar®. Kevlar® is the trade name for the aramids fibers. It has these properties:

[23] The earliest composite boat was the dinghy Tod 12 and was built in 1951, only 12 years before the 470 was designed.

- High specific resistance to traction, compared with other known materials.
- Excellent impact resistance. High energy absorption capacity.
- Lower density than all synthetic fibers used in laminates.
- Excellent against corrosion in any environment.
- Good resistance to fatigue.
- Good damping characteristics of vibration.
- Negative expansion coefficient.
- Breakage occurs progressively.
- UV rays affect the outer layers of kevlar®, although the degradation is usually no progressive.
- The cost is considerable, a fact which limits their usefulness.

The table below compares relevant characteristics between the three fibers.

Fiber	**Tensile(GPa)**	**Density (Kg/m3)**	**Elongation at brake(%)**
Fiber glass	3,4	2500	4,5
Carbon	4	1800	2
Kevlar®	3,4	1450	2,2

32, Fiber comparing chart. Own source

Regarding resins exist wide kinds of resin but many of them not fit in boatbuilding like these ones do:

The polyester resin which is the most used[24] and the cheapest. Its resistance and stiff are not so good. During the hardening tends to shrink from 6 to 10%.

The vinylester can be defined as the resin between the polyester and the epoxy. Vinylester has better mechanical properties and chemical properties than the polyester, has a high degree of resilience, good resistance to fatigue and shrink during cure is much lower than polyester resins with 1%. The price is almost twice the polyester.

The third resin use in high demands applications is the epoxy. Epoxy has better physical and mechanical properties and resistance to abrasion and chemical agents than polyester

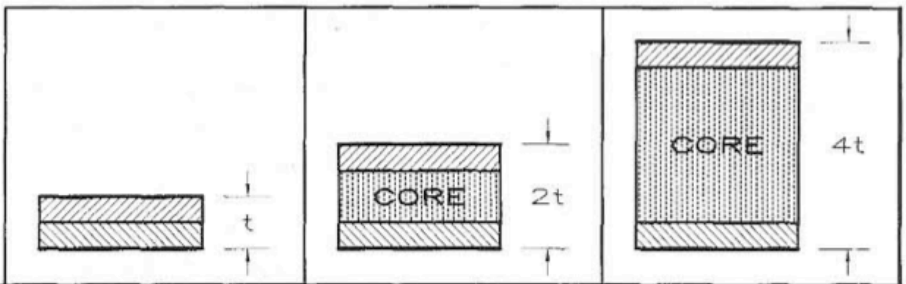
[24] Over 90% of the world consumption volume.

and vinylester. Add to this his great capacity for adhesion a wide range of reinforcing materials, results in laminates with high fibre content. The contraction during curing is negligible (0-1%).

From all the fibres and resins I decided to use polyester fibre which is the cheapest and satisfy the demands, and use epoxy resin which allow high fibre content in the composite boosting its properties. By this changes I'll achieve a lighter hull and what I think is most important, a longer life for the boat.

Moreover there's something that improve the mechanic properties with almost no weight cost and is using a sandwich structure.

A sandwich is a lamination structure with fibre on the sides and a core of another material. This core material is so light and what do is bringing thickness to the structure. As you can see in the chart below the relative stiffness almost multiply by 7 each time you double the thickness. The strength is triplicate and the weight just increase a modest 3% each time.



Relative Stiffness	100	700	3700
Relative Strength	100	350	925
Relative Weight	100	103	106

33. Strength and stiffness in sandwich vs solid. Source: Principles of Yacht Design, Lars Larsson

As a sandwich structure core there're hundreds of materials and structures from wood to complex honeycomb, and each year new materials and structures appears so limiting the material and the structure would be unfair at this point of design and what I decide to do is restrict a minimum density of 50Kg/m³.

Hull Conclusions

In conclusion, the hull have changed the deck and the structure to improve de dynamism and increase the lifetime; the production has changed to an easy process which achieve best results easily, has less costs and pollutes less; and the change of materials in the building cause lifetime increasing and a reduced weight.

10. Conclusions

Even in each chapter I have extracted conclusions for each topic I think that is important to resume them here, comparing straight the results with the improvement targets and obtain global conclusions and the best solutions.

As you may remember, I relied targets with keywords which must have improved if the boat has gotten better. First of all let's see one by one the keywords and if have been changed or not.

- Speed: The speed must increase. Regard to the sails, V1 and V3 versions have increased the sail plan specially downwind so the speed in light winds and downwind has grown. The use of higher aspect-ratio sails and full-battens make the sail more efficient therefore the achieved speed is higher. And the reef system in V3 sails avoid loosing speed over the sails design point.

The new mast achieves completely freedom in mast trim by not narrowing the mast bend, and by the low spreaders system you can set accurately the trim and achieve speed.

The hull with less weight and more centered plane earlier, so you achieve more speed with less wind.

- Acceleration: By using high aspect-ratio sails, bigger sail plans and less weight in mast and hull, the acceleration must increase a bit on V1 version which just change the sails, increase more in V3 sails with the new mast and boost in V3 sails with mast and hull changed.

- Agility: The new spinnaker dropping system can reduce the spinnaker drop maneuvers to half of the time, what report faster marks pass. I can qualify of agility the low spreaders regulation system for mast trimming. The reef system incorporates a new factor while racing because is limited to one move of the main halyard each race.

- Comfort: The deck has almost double the cockpit, therefore there are more space. The disappearance of the side tanks in the crew area allows the crew to move easier and go out to the trapeze faster while at the same time the helm is kept sitting comfortable in the tank. The disappearance of the spinnaker bags leave that area free for the crew to go forward with light winds.

- Compact: Thanks to the new mast and the big cockpit the boat can be set out without overlapping the hull. Fit boats on a trailer or in a container is children's game. And with the new structure the boat will suffer less when is on the trolley o capsize in the trailer.

- Media: Hundreds of media options already exist nowadays but without engaged spaces any try of insert media in the boat is a challenge. Now with two specific places for cameras and one box for electronics gadgets is easy.

- Affordability: Regarding the sails I look for affordability by opening the use of new sails cloth. That may seems contradictory but to avoid a material war I narrow the weight, and the number of sails per year. With these measures I allow people to keep being competitive with today sails material and new materials just can improve in durability so in mid or long term the decision of leave the sail cloth free to choose by the sailor entail affordability. And the reef system prolongs the main life, keeping it safe with breeze.

About the new rig I could say that a carbon mast fatigues are lower than aluminum and the requiring of a floating spinnaker pole ensures that you don't lose it in the first capsize. The hull has multiplied the life of the boat. Structural problems and hull deformations must arrived to their end.

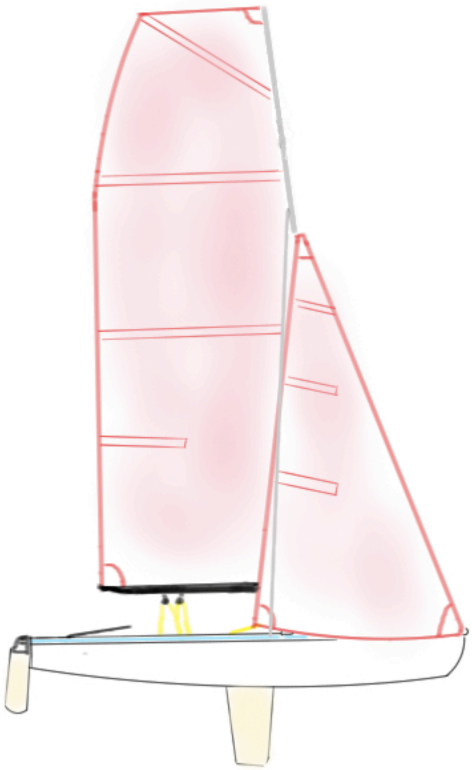
But there're some other aspects which have improved with new models.

As we have seen from the beginning fancy people is one of the important aspects of the project, spectacularity is important and I've tried to appeal people by using colors for seams and finishes in the sails, a more striking logo, and promising spectacular pictures even in light winds because of speed, acceleration and agility.

Other important aspect is that by using new building methods and forcing use new long life materials the boat becomes friendlier to the environment with less chemical emissions during the building process, less material to build each boat, a less boats thrown away each year.

These have been all the improvements in the 470 modification. From all of those I've divided the improvements in equipments to carry out them. And from these divisions have appeared three final possible "models". I specify them here and I attached a sketch to transmit better the global idea and compare them with the current boat:

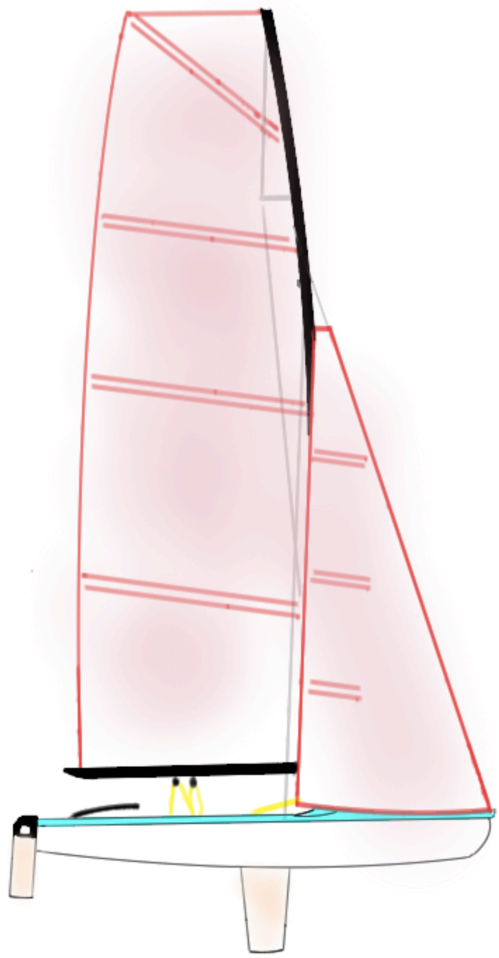
34. Side view of the current 470. Own source



The first model incorporates the V1 sails with the current mast and hull. So it's different in the sail plan only. The boat will be faster in light winds and will begin to plan earlier, but is not a huge change in compare with others new models. This change just ensures low cost in sails. The mast may reduce his live.

35. Side View of the first model. Own Source.

The second model is the boat with the current hull but with a completely new sail plan and mast. In V3 the sail plan is huge compared with the current sail plan, the speed is boosted and some new systems appear. The boat increases his appeal significantly. The change is cheap if you worth the appealing improvement, the speed achieved and the durability of mast and sails.



36. Side view of the second model or third model. Own source.

The third model implies a change of almost all the current equipment; sails, rig and hull. Even so is the best in performance and the cheapest long term. Planing with this model must be the rule.

11. Project Evaluation

I'm happy about the results and conclusions of this project. When I began the project I'd sailed a lot in 470 and I'd been in a lot of 470 regattas and I'm sure that I couldn't have learned about this boat and the class in the same way anywhere. But by studying which is the actual situation of the class relative to other, Olympic or in expansion, classes I've seen clearly that changes are necessary.

And it was when I sit and I began to dream in better boat that I realized that a better boat in each aspect was going to be impossible. More speed, more acceleration, more spectacularity, life longer and cheaper!

On the contrary changes done are real, and the boat has been able to achieve all the targets. So in my opinion, the biggest conclusion have been:

The 470 needs a change, and this change is real and affordable.

Appendix 1

Current 470 Rules

INTERNATIONAL
470
CLASS RULES
2011

The 470 was designed in 1963 by Andre Cornu and was adopted as an international/recognised class in 1969.

INDEX

INTRODUCTION 3

PART I – ADMINISTRATION

Section A – General

A.1 Language 4
A.2 Abbreviations 4
A.3 Authorities and Responsibilities 4
A.4 Administration of the Class 4
A.5 ISAF Rules 5
A.6 Class Rules Variations 5
A.7 Class Rules Amendments 5
A.8 Class Rules Interpretations 5
A.9 International Class Fee and ISAF Plaque 5
A.10 Sail Numbers 5
A.11 Hull Certification ....5 - 6
A.12 Initial Hull Certification 6
A.13 Validity of Certificates 6
A.14 Hull Re-Certification 6
A.15 Retention of Measurement Forms 6

Section B – Boat Eligibility

B.1 Class rules and Certification 7
B.2 Flotation Check 7
B.3 Class Association Sticker 7

PART II – REQUIREMENTS AND LIMITATIONS

Section C – Conditions for Racing

C.1 General 8
C.2 Crew 8
C.3 Personal Equipment ....8 - 9
C.4 Advertising 9
C.5 Removable Equipment 9
C.6 Boat 9
C.7 Hull 10
C.8 Hull Appendages 10
C.9 Centreboard ....10 - 12
C.10 Rudder Blade, Stock and Tiller ....12 -15
C.11 Rig 15
C.12 Mast ....15 - 18
C.13 Boom ....18 - 19
C.14 Spinnaker Pole ....19 - 20
C.15 Standing Rigging 20
C.16 Running Rigging ....20 - 21
C.17 Sails ....21 - 22

Section D– Hull

D.1 General ....23 - 24
D.2 Buoyancy Tanks 24
D.3 Assembled Hull ....24 - 26
D.4 Measurement Diagrams....26 - 30

Section E – Hull Appendages

- Not in use ....-

Section F – Rig

- Not in use ....-

Section G – Sails

G.1 Parts 31
G.2 General 31
G.3 Mainsail ....31 - 33
G.4 Headsail 33
G.5 Spinnaker ....33 - 34

INTRODUCTION

This introduction only provides an informal background and the International 470 Class Rules proper begin on the next page.

The 470 is a One-Design racing dinghy with an overall length of 4.70m for a crew of two, designed by Andre Cornu in 1963 and adopted as an International/Recognized class in 1969 and became an Olympic Class in 1976 where the class was sailed as an open event before the introduction of separate events for men and women in 1988.

Class rules may evolve, while the intention is to avoid the use of costly, short-lived, risky or environmentally improper materials.

470 hulls, hull appendages, rigs and sails are measurement controlled.

Rules regulating the use of equipment during a race are contained in Section C of these class rules, in ERS Part I and in the Racing Rules of Sailing.

Owners and crews should be aware that compliance with rules in Section C is not checked as part of the certification process.

PART I – ADMINISTRATION

Section A – General

A.1 LANGUAGE

A.1.1 The official language of the class is English and in case of dispute over translation the English text shall prevail.

A.1.2 The word “shall” is mandatory and the word “may” is permissive.

A.1.3 The term "secured" shall mean held in place by positive means.

A.1.4 The term "fastened" shall mean held in place with bolts or screws.

A.1.5 The term "permanent" shall mean unable to be removed with simple tools, or fixed with glue or rivets. For limit marks, it shall mean unable to be removed and repositioned without destroying them.

A.1.6 The term "alteration" shall mean a substantial change from the original condition.

A.1.7 A dimension or other requirement in the text overrides the same in a Figure.

A.1.8 All units are metric.

A.1.9 All dimensions are in millimetres.

A.1.10 Drawings generally show the transom to the left and the stem to the right, measuring is usually from left to right, but for practical reasons some drawings are tilted.

A.2 ABBREVIATIONS

A.2.1

ISAF	International Sailing Federation
MNA	ISAF Member National Authority
ICA	International 470 Class Association
NCA	National 470 Class Association
ERS	Equipment Rules of Sailing
RRS	Racing Rules of Sailing

A.3 AUTHORITIES

A.3.1 The international authority of the class is the ISAF, which shall co-operate with the ICA in all matters concerning these **class rules**.

A.3.2 Neither the ISAF, an MNA, the ICA, an NCA, a certification authority, or an official measurer are under any legal responsibility in respect of these class rules and the accuracy of measurement, nor can any claims arising from these be entertained.

A.3.3 Notwithstanding anything contained herein, the certification authority has the authority to withdraw a certificate and shall do so on the request of the ISAF.

A.4 ADMINISTRATION OF THE CLASS

A.4.1 ISAF has delegated its administrative functions of the class to MNAs. The MNA may delegate part or all of its functions, as stated in these **class rules**, to an NCA.

A.4.2 In countries where there is no MNA, or the MNA does not wish to administrate the class, its administrative functions as stated in these **class rules** shall be carried out by the ICA which may delegate the administration to an NCA.

A.5 ISAF RULES

A.5.1 These **class rules** shall be read in conjunction with the current version of ERS.

A.5.2 Except where used in headings, when a term is printed in "**bold**" the definition in the ERS applies and when a term is printed in "*italics*" the definition in the RRS applies.

A.5.3 These rules are complementary to the Building Specification Plan and Measurement Form.

A.6 CLASS RULES VARIATIONS

A.6.1 At World, Continental or Regional Championships the notice of race and sailing instructions may change the **class rules** only with the agreement of the ICA and the ISAF.

A.6.2 At National events the notice of race and sailing instructions may chnage the **class rules** only with the agreement of the NCA and the MNA.

A.6.3 At class events, these **class rules** shall not be varied by the notice of race and sailing instructions except as provided by A.6.1.

A.7 CLASS RULES AMENDMENTS

A.7.1 Amendments to these **class rules** are subject to the approval of the ISAF in accordance with the ISAF Regulations.

A.8 CLASS RULES INTERPRETATIONS

A.8.1 Interpretation of **class rules** shall be made in accordance with the ISAF Regulations.

A.9 INTERNATIONAL CLASS FEE AND ISAF BUILDING PLAQUE

A.9.1 The licensed hull builder shall pay the International Class Fee.

A.9.2 ISAF shall, after having received the International Class Fee for the hull, send the ISAF Building Plaque and a measurement form to the licensed hull builder.

A.10 SAIL NUMBERS

A.10.1 Sail numbers shall be issued by the MNA of the country where the boat is registered, which may delegate this function to the NCA.

A.10.2 Sail numbers shall be issued in consecutive order starting at "1".

A.10.3 In accordance with ISAF RRS Appendix G1.1 (c), the MNA or NCA may issue personal sail numbers (Sail numbers staying with the owner for every boat he legally possesses as long as he sails 470) for which the authority may raise a fee. This number must be shown on the Certificate and shall not conflict with existing numbers of active boats. After the sale of the boat, the new owner has to use her original sail number or his own personal number on his sails.

A.10.4 Competitors may use the sail number of any hull still owned by them, on any boat chartered or owned by them.

A.11 HULL CERTIFICATE

A.11.1 No boat shall take part in class races unless it has a valid measurement certificate in the owner's name. The measurement certificate is only valid if the owner is a current member of a national 470 Class Association or, if there is no national 470 Class Association in his nation, member of the 470 International.

A.11.2 A **certificate** shall record the following information:

(a) Class

(b) **Certification authority**

(c) Sail number(s)in accordance with A.10.

(d) Owner's name and address.

(e) Hull identification *(see D.1.4)*

(f) Builder / manufacturer's details

(g) Date of issue of initial cer**tificate**

(h) Date of issue of **certificate**

(i) Measurer's name.

A.12 INITIAL HULL CERTIFICATION

A.12.1 For a **certificate** to be issued to a hull not previously **certified**:

(a) **Equipment certification control** shall be carried out by an **official measurer.**

(b) The measurement form(s), and **certification** fee, if required, shall be sent to the **certification authority**.

(c) Upon receipt of a satisfactorily completed measurement form(s) and **certification** fee, if required, the **certification authority** may issue a **certificate**.

A.13 VALIDITY OF CERTIFICATES

A.13.1 A hull **certificate** becomes invalid upon:

(a) the change to any items recorded on the hull **certificate** as required under A.11.2

(b) the date of expiry or change of ownership**,**

(c) withdrawal by the **certification authority**,

(d) the issue of a new **certificate.**

A.13.2 Older hulls need not be re-certified if the rules under which they were built are changed (grandfather rule).

A.14 HULL RE-CERTIFICATION

A.14.1 The **certification authority** may issue a new **certificate** to a previously certified hull:

(a) When the certificate has become invalid under A.13.1 (a) or (b), after receipt of the old **certificate**, and **certification** fee if required.

(b) When the certificate has become invalid under A.13.1 (c), at its discretion.

(c) In other cases, by application of the procedure required for initial hull **certification.**

A.15 RETENTION OF MEASUREMENT FORMS

A.15.1 The **certification authority** shall;

(a) retain the original measurement form(s) upon which the current certificate is based,

(b) upon request, transfer those measurement form(s) to the new certification authority if the hull is exported.

Section B – Boat Eligibility

For a **boat** to be eligible for *racing*, it shall comply with rules in this section.

B.1 CLASS RULES AND CERTIFICATION

B.1.1 The boat shall;

(a) Be in compliance with the **class rules**.

(b) Have a valid hull **certificate**.

(c) have valid **certification marks** as required

B.2 TAGS

B.2.1 At championships or principal events the race committee may arrange for boats and/or sails to be partly or completely re-measured before racing. Parts measured shall be marked with a tag (sticker/stamp which may be signed and numbered by the Measurer). Tags of previous events shall be ignored.

B.3 FLOTATION CHECKS

B.3.1 It is the responsibility of the owner to ensure at all times the water tightness of the boat.

B.4 CLASS ASSOCIATION STICKER AND LABELS

B.4.1 A valid class association sticker, if required by the NCA, shall be affixed to the **hull** or hull **certificate** in a conspicuous position.

B.4.2 Sails shall carry a sail button / sticker issued by the ICA.

PART II – REQUIREMENTS AND LIMITATIONS

The **crew** and the **boat** shall comply with the rules in Part II when *racing*. Measurement to check conformity with rules of Section C is not part of **equipment certification control.**

The rules in Part II are **closed class rules**. Measurement shall be carried out in accordance with the current version of ERS except where varied in this Part.

Fittings may be combined as long as no additional function is added

Section C – Conditions for Racing

C.1 GENERAL

C.1.1 RULES

(a) The following RRS 2009-2012 rules shall apply as amended below:

(1) If the average wind speed is above 8 knots, measured at deck level, the race committee may permit pumping, rocking and ooching after the starting signal. (change of RRS 42.2(a), RRS 42.2(b), RRS 42.2(c))._ The signals will be made according to RRS P5._

(2) A trapeze system may be used (change of RRS 49.1).

(b) The ERS Part I – Use of Equipment shall apply.

C.2 CREW

C.2.1 LIMITATIONS

(a) The **crew** shall consist of two persons.

(b) No **crew** member shall be substituted during an event, unless authorised by the Race Committee.

(c) The trapeze system shall not be used by more than one **crew** member at any time.

C.3 PERSONAL EQUIPMENT

C.3.1 MANDATORY

(a) The boat shall be equipped with personal buoyancy for each **crew** member to the minimum standard ISO 12402 Level 50, or USCG Type III, or AUS PFD 1 or equivalent. Inflatable buoyancy vests are not permitted.

C.3.2 OPTIONAL

(a) Trapeze harness. The weight shall not exceed 3 kg, measured according to current version of RRS, appendix H.

C.3.3 TOTAL WEIGHT

(a) The total weight of personal equipment worn, excluding trapeze harness, shall not exceed 9 kg, measured according to current version of RRS, appendix H.

C.4 ADVERTISING

C.4.1 LIMITATIONS

Advertising shall only be displayed in accordance with the ISAF Advertising Code. See ISAF Regulation 20.

C.5 REMOVABLE EQUIPMENT

C.5.1 FOR USE

(a) OPTIONAL

(1) One hand bailer or bucket.

(2) Up to two compasses, which may be included in timing devices. If electronic, only compasses with heading, heading memory and timing functions are permitted.

(3) Electronic or mechanical timing devices which may include a compass, and which shall be removable. Wrist watches with compass functionality are permitted additionally. No other electrical or electronic devices than those prescribed in C.5.1 and those required by an organizer and the ICA to be carried by boats shall be permitted on board when racing.

C.5.2 NOT FOR USE

(a) OPTIONAL

(1) One paddle.

(2) Spare parts such as blocks, shackles, ropes, etc…

(b) MANDATORY

(1) Towing rope of floating type with a minimum length of 10m and of not less than 8mm in diameter.

C.6 BOAT

C.6.1 WEIGHT

	minimum
The weight of the **boat** shall be	120 kg,
measured with the **boat** in dry condition, including compasses, but excluding **sails,** jib luff wire and all removable equipment.	

C.6.2 CORRECTOR WEIGHTS

(a) When the **boat** weight is less than the minimum, **corrector weights** shall be fastened under the mast partner or to the top of the forward bulkhead.

(b) The total weight of such **corrector weights** shall not exceed 2.0 kg.

C.6.3 FLOTATION

(a) If in doubt regarding compliance with B.3, an **equipment inspector** may order a buoyancy test, afterwards checking the tanks for significant leakage. If the buoyancy is deemed unsatisfactory, the **certificate** shall be withdrawn and not returned until satisfactory remedial measures have been taken.

C.6.4 All fittings, fastenings and local reinforcement for fittings shall be only for their normal purpose and shall not be used to increase the weight of the **boat**.

C.7 HULL

C.7.1 MODIFICATIONS AND MAINTENANCE

(a) The hull shell, deck, bulkheads and cockpit floor as supplied by the licensed builder shall not be altered in any way except as permitted by these **class rules**.

(b) Routine maintenance such as small repairs, painting, sanding and polishing is permitted without re-measurement and re-**certification**.

(c) If any hull moulding is repaired in any other way than described in C.7.1(b), an **official measurer** shall verify on the **certificate** that the external shape is the same as before the repair and that no substantial increase in stiffness, or other, advantage has been gained as a result of the repair. The **official measurer** shall also describe the details of the repair on the **certificate**.

(d) Non-slip material, tape and low-friction material not exceeding 4mm in thickness may be added to the **boat** as long as it does not change the stiffness of the **hull**.

C.7.2 FITTINGS

(a) USE

(1) Inspection hole covers and drainage plugs shall be kept in place at all times when racing.

(2) Except when specified otherwise or a system is optional, the direction of the control lines, sheets and ropes shall not be modified by means of shackles, rings, loops or holes in the boat.

C.8 HULL APPENDAGES

C.8.1 MANUFACTURERS

(a) Manufacturer is optional.

C.8.2 LIMITATIONS

(a) Only one **centreboard** and one **rudder** blade shall be used during an event, except when a **hull appendage** has been lost or damaged beyond repair.

C.9. CENTREBOARD

C.9.1 MATERIALS

The **centreboard** shall be made from one or a combination of the following materials; wood, plywood, polyester reinforced with glass fibre, epoxy reinforced with glass fibre and/or plastic foam which includes micro balloons and may be painted.

C9.2 FITTINGS

OPTIONAL

(1) Blocks and associated fittings for hoisting/lowering the **centreboard.**

(2) A bushing round the pivot of the centreboard.

C.9.3 DIMENSIONS

(a) Dimensions shall conform to the centreboard measurement diagrams as shown in C.9.4.

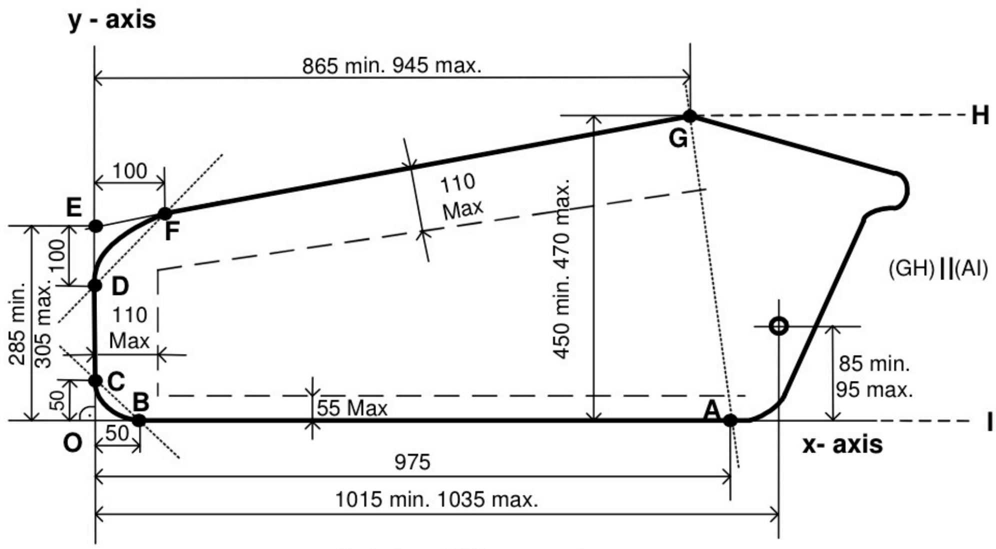
(b) The **centreboard** shall be of even thickness throughout, minimum 20mm and maximum 24 mm, except that the edges may be bevelled over distances of 110 mm from the trailing and lower edges, and 55 mm from the leading edge.

(c) Except for permitted bevelling, the thickness shall not vary by more than 1 mm.

(d) The **centreboard** shall not be pierced by lightening holes.

C.9.4 CENTREBOARD MEASUREMENT DIAGRAMS

The contour of the centreboard is defined by the points A, origin O, E, G, the lines (GH) and (AI), as Figure “Centreboard Measurement” shows.



Centreboard Measurement

(a) DEFINITIONS OF MEASUREMENT POINTS AND LINES

The centreboard shall touch points A, B and C. These points are integral to the centre board.

The x and y axes are square to each other.

A is the point on the x-axis 975mm from the origin O.

B is the point on the x-axis 50mm from the origin O.

C is the point on the y-axis 50mm from the origin O.

Point F is the point on the trailing edge 100mm from the y-axis.

Point G is the widest point of the centreboard on the trailing edge.

Point E is the extension of the trailing edge (FG) on the y-axis.

Point D is the point on the lower edge 100mm from point E, measured along the y-axis. It shall be no more than 2mm from the y-axis.

(b) DIMENSIONS

	minimum	maximum
Distance from the centre of the pivot hole to the x–axis	85 mm	95 mm
Distance from the centre of the pivot hole to the y–axis	1015 mm	1035 mm
Distance from E to the x–axis	285 mm	305 mm
Distance from G to the outmost point of the leading edge (AB)		470 mm
Distance from G to the innermost point of edge (AB)	450 mm	
Distance from G to the y–axis	865 mm	945 mm
Total (positive, negative or both) deviation of an edge from a straight line:		
Between points A and B from the x–axis		2 mm
Between points C and D from line (CD)		2 mm
Between points F and G from line (FG)		2 mm

Line (AI) lies on the x-axis. Line (GH) is parallel to the x-axis. The length of the lines (AI) and (GH) is arbitrary. The contour of the centreboard inside the area AGHI is free, but no part of the centreboard shall lie outside this area.

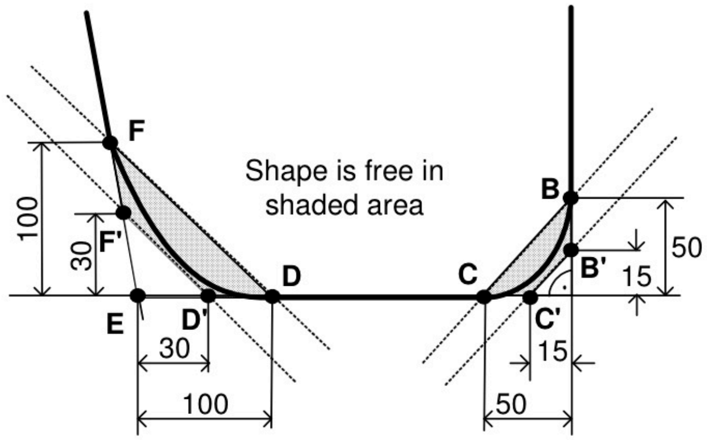
The shape of the lower corners of the centreboard shall lie within the shaded areas in the Figure "Centreboard Lower Edge Shape", and no part of the bottom edge of the centreboard shall lie outside the polygon formed between points B, B', C', D', F' and F.

Point B' is the point on the x-axis 15mm from origin O.

Point C' is the point on the y-axis 15mm from origin O.

Point D' is the point on the y-axis 30mm from point E.

Point F' is the point on line (EG), 30mm from point E.



Centreboard Lower Edge Shape

C.9.5 WEIGHTS

	minimum	maximum
(1) Weight in dry condition excluding fittings	4.5 kg	6.5 kg

(2) Corrector weights are not permitted.

C.9.6 CONDITIONS FOR USE

(a) No part of the **centreboard**, in its raised position, shall project below the **hull**.

C.10 RUDDER BLADE, STOCK AND TILLER

C.10.1 MATERIALS

(a) The **rudder** blade shall be made of one or a combination of the following materials; wood, plywood, polyester with glass fibre, epoxy with glass fibre and/or plastic foam, which includes micro balloons and may be painted.

(b) For boats first **certified** after 1st March 2002, the rudder stock and tiller shall be made of aluminium alloy and/or stainless steel.

(c) The rudder stock shall not act as an extension of the hull

C.10.2 FITTINGS

(b) OPTIONAL

(1) Control lines and two cleats may be used to fix the position of the rudder blade. One block per cleat is permitted.

(2) A bushing round the pivot of the rudder blade

(3) The control lines may be fixed on the rudder blade by an eye-bracket.

(4) A tiller extension, which may be telescopic and of any material.

C.10.3 DIMENSIONS

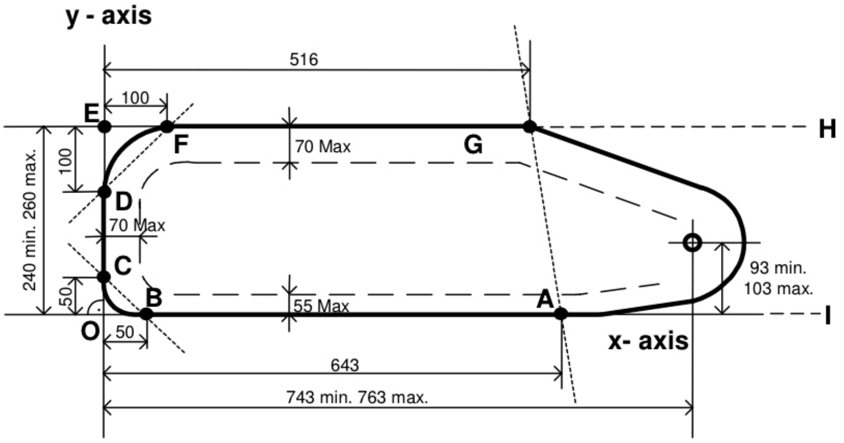
(a) Dimensions shall conform to the Rudder measurement diagrams as shown in C.10.4

(b) The rudder blade shall be of even thickness throughout, minimum 20mm and maximum 24 mm, except that the edges may be bevelled over distances of 70mm from the trailing and lower edges and 55mm from the leading edge.

(c) Except for permitted bevelling, the thickness of the rudder blade shall not vary by more than 1 mm.

C.10.4 RUDDER MEASUREMENT DIAGRAM

The contour of the rudder is defined by the points A, origin O, E, G, and lines (GH) and (AI), as Figure "Rudder Blade Measurement" shows.



Rudder Blade Measurement

(a) DEFINITIONS OF MEASUREMENT POINTS AND LINES

The rudder blade shall touch points A, B and C. These points are integral to the rudder blade.

The x and y axes are square to each other.

A is the point on the x-axis 643mm from the origin O.

B is the point on the x-axis 50mm from the origin O.

C is the point on the y-axis 50mm from the origin O.

Point F is the point on the trailing edge 100mm from the y -axis.

Point G is the point on the trailing edge 516mm from the y -axis.

Point E is the extension of the trailing edge (FG) on the y - axis.

The trailing edge (FG) is parallel to the x–axis: the distance of point (G) from the outmost point of the leading edge, measured along y-axis, shall be equal to width (OE) within 2mm.

Point D is the point on the lower edge 100mm from point E, measured along the y-axis. It shall be no more than 2mm from the y-axis.

(b) DIMENSIONS

	minimum	maximum
Distance from the centre of the pivot hole to the x–axis	93 mm	103 mm
Distance from the centre of the pivot hole to the y–axis	743 mm	763 mm
Distance from E to the x–axis	240 mm	260 mm

Total (positive, negative or both) deviation of an edge from a straight line:

Between points A and B from the x–axis .... 2 mm

Between points C and D from line (CD) .... 2 mm

Between points F and G from line (FG) .... 2 mm

At no point the width of the rudder blade shall be more than 260mm or less than 240mm.

Line (AI) lies on the x-axis. Line (GH) is parallel to the x-axis. The length of the lines (AI) and (GH) is arbitrary. The contour of the rudder blade inside the area AGHI is free, but no part of the rudder shall lie outside this area.

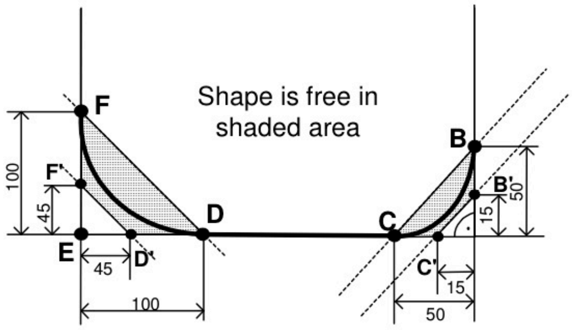
The shape of the lower corners of the rudder blade shall lie within the shaded areas in the Figure “Rudder Blade lower Edge Shape” and no part of the bottom edge of the rudder shall lie outside the polygon formed between points B, B’, C’, D’, F’ and F.

Point B’ is the point on the x-axis 15mm from origin O.

Point C’ is the point on the y-axis 15mm from origin O.

Point D’ is the point on the y-axis 45mm from point E.

Point F’ is the point on line (EG), 45mm from point E.



Rudder Blade Lower Edge Shape

C.10.5 WEIGHTS

	minimum	maximum
The rudder blade, dry, with control ropes only:	2.3kg	

If the rudder blade is found to be underweight the difference shall be made up by corrector weights permanently fastened to the upper edge surface.

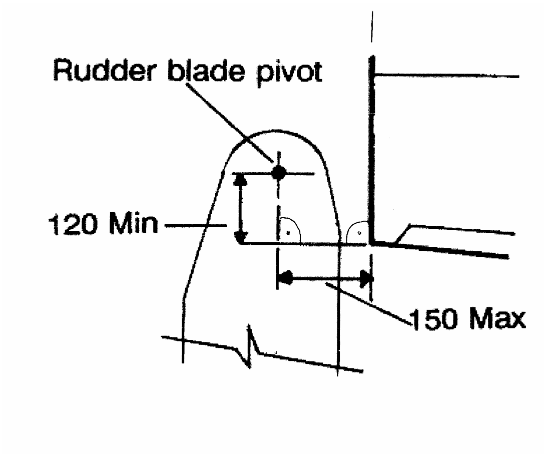
C.10.3 CONDITIONS FOR USE RUDDER

(a) The **rudder** blade shall be in its fully lowered position. However for races sailed in shallow water, the sailing instructions may prescribe that this rule shall not apply.

(b) RUDDER ASSEMBLY

The rudder consists of a rudder blade, a rudder stock and a tiller. The rudder blade shall be able to pivot around its axis. The rudder shall be detachable from the hull.

When mounted on the hull, the rudder blade pivot shall be located at a maximum of 150 mm abaft the transom and its height above the lower corner of the transom shall be a minimum of 120 mm, measured according to the Figure “Rudder Pivot Position”.



Rudder Pivot Position

C.11 RIG

C.11.1 LIMITATIONS

(a) Only one mast, boom and spinnaker pole shall be used during an event except when an item has been lost or damaged beyond repair.

C.11.2 DEFINITIONS

(a) MAST DATUM POINT

The **mast datum point** (MDP) is the **heel point**. Unless indicated otherwise, all measurements are from the MDP.

C.11.3 MANUFACTURER

(a) **Spar** manufacturer is optional.

C.12 MAST

C.12.1 MATERIALS

(a) The **spar** shall be of aluminium alloy.

C.12.2 CONSTRUCTION

(a) The **spar** shall include a fixed sail groove or track, which may or may not be integral with the **spar**.

C.12.3 FITTINGS

(a) MANDATORY

(1) A goosneck

(2) Kicking strap attachment

(3) Spinnaker pole fitting.

(4) Spinnaker pole downhaul blocks and/or sheave boxes with attachment.

(5) Spinnaker pole lift blocks and/or sheave boxes with attachment.

(6) A pair of fixed or adjustable metal **spreaders** with optional attachment systems which may include local reinforcement as per C.12.4

(7) Headsail halyard block(s) and or sheave box(es).

(8) Attachments for shrouds, forestay and trapezes.

(9) Spinnaker halyard blocks and/or sheave boxes.

(10) A sheave or sheave box and a rack lock or cleat for the mainsail halyard.

(11) A device to ensure compliance with ERS B.9.1 (a) if the mainsail halyard system itself does not do so.

(12) Permanently painted/taped **limit marks**.

(b) OPTIONAL

(1) A heel fitting

(2) A fitting for centreboard hoist blocks.

(3) Mainsail halyard blocks and/or sheave boxes.

(4) Headsail halyard cleat

(5) Fitting(s) for Cunningham adjustment.

(6) Reinforcement at mast partner as per C.12.4.

(7) A removable timing device

(8) Attachment fittings for removable compass.

(9) A fitting to attach mainsail **tack** to **spar**

(10) Devices attached to the **spreaders** to prevent the spinnaker halyard from getting tangled

(11) A spinnaker crane which may include sheaves, blocks and/or fairleads for spinnaker halyard

(12) A masthead fittings which may include a mainsail halyard sheave.

(13) One mechanical wind indicator.

C.12.4 DIMENSIONS

	minimum	maximum
Mast spar deflection when loaded at 3500 mm from the **mast datum point,** and supported horizontally at the **upper point** and a point not more than 100mm from the heel:		
fore-and-aft (load 25kg)		200 mm
transverse (load 15kg)		130 mm
permanent bend **fore-and-aft**		40 mm
Mast spar cross section between MDP and 5010 mm;		
Transverse	55 mm	75 mm
Mast spar cross section between 1550 mm and 5010 mm;		
fore-and-aft	65 mm	75 mm

In this region the mast section shape and wall thickness excluding external luff groove shall be constant along the length of the spar. Reinforcement is permitted in the regions of the mast partner, spreaders and the connection if the mast is made of two parts. A cut-off for sail entry is permitted.

Mast limit mark width	10 mm	
Lower point height		1055 mm
Upper point to the **lower point**		5750 mm
Forestay height	4995 mm	5025 mm
Trapeze height	4910 mm	5110 mm
Shroud height	4995 mm	5025 mm
Spinnaker pole fitting:		
height	1240 mm	1260 mm
projection		40 mm
Spinnaker hoist height		5170 mm
Spinnaker halyard projection device, distance from **spar**		60 mm
Spreader height	2790 mm	2810 mm
The Distance between **mast datum point** and the intersection of the **spar** and the lower edge of the jib halyard, when at 90^0 to the spar, each extended as necessary	4870 mm	
Distance from **mast datum point** to centre of gravity in condition as described in ERS H.4.6. The rigging parts to be included in the measurement are those under C.15.2; C.16.2 (a). The trapeze system shall only include the wire and the grip. The ends of the halyards are to be left on the ground	2800 mm	
Distance between the aft face of the mast and the gooseneck pivot		35 mm

C.12.5 WEIGHTS

The weight of the **mast** includes rigging specified under C.15.2; C.15.3 (a) (1), C.16.2 (a), fittings specified under C.12.3 and permanently fastened compass bracket if applicable, but without wind indicator, compass and/or timing device:

	minimum	maximum
Mast weight	10 kg	
Mast corrector weights		0.3 kg

Corrector weights shall be permanently fastened so that no part of the corrector is more than 200mm from the **upper point.**

C.12.6 CONDITIONS FOR USE

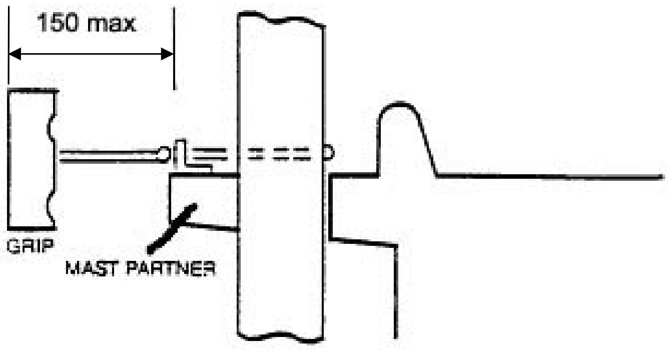
(a) USE

(1) The fore and aft bend of the mast **spar** may be controlled at the mast partner by one of the following devices:

(i) Chocks between the mast **spar** and the mast partner (forward of the mast).

(ii) Optional systems of ropes or wires which may include attachments, blocks, levers, grips and cleats, all located on top of the mast partner.

With the mast spar in its most forward position, the grip, end of rope, wire or other parts of the system of the aft bend control shall not be more than 150mm from the mast partner as Figure "Mast Controller Grip" shows:



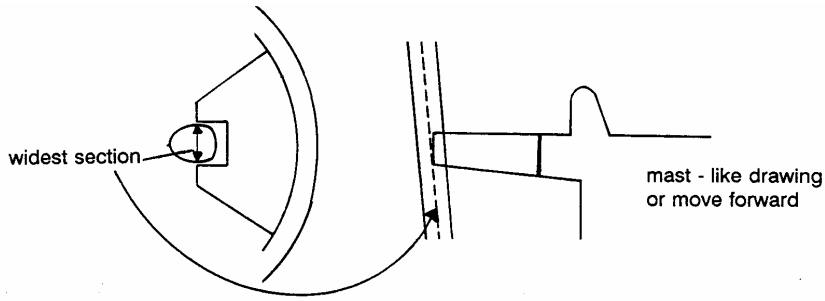
Mast Controller Grip

With the mast in its aft most position the grip of the forward bend control shall not be more than 150mm from the mast partner.

(2) The sideways play between the **mast spar** and the mast partner may be controlled by strips of any material permanently fastened to the mast partner.

(3) The mast heel position shall not be adjusted when *racing*.

(4) The forestay under tension shall be entirely in metal and shall prevent the mast from disengaging from the mast partners. To meet this requirement the widest section of the mast shall be within the mast partners when the mast rakes under its own weight and the forestay comes under tension, as Figure "Mast Rake with Tensioned Forestay" shows:



Mast Rake with Tensioned Forestay

(5) Adjustable spreaders if used shall not be remotely controlled, and shall not be adjusted when racing.

C.13 BOOM

C.13.1 MATERIALS

(a) The boom **spar** shall be of aluminium alloy.

C.13.2 CONSTRUCTION

(a) The **boom** shall include a fixed aluminium sail groove or track which may or may not be integral with the **spar**.

C.13.3 FITTINGS

(a) MANDATORY

(1) A gooseneck attachment.

(2) A kicking strap fitting.

(3) Mainsheet block(s) with attachment fitting(s) for the blocks and/or mainsheet which may be adjustable

(4) Mainsail **clew** outhaul attachment or adjustment system.

(5) A stopper to ensure compliance with C.17.4.(b).(4).

(6) Permanently painted/taped **limit mark**.

(b) OPTIONAL

(1) A fitting to attach mainsail **tack**

(2) An aft **spar** end fitting

(3) The **spar** may be protected in the area where it touches the shrouds by pieces of any material, with maximum length/height/thickness=100/50/5 mm.

C.13.4 DIMENSIONS

	minimum	maximum
Boom spar deflection when loaded with 80 kg at a point midway between points 100 mm from each end and with the groove uppermost:		
vertical		50 mm
Boom spar cross section		
vertical	54 mm	72 mm
transverse	38 mm	
Radius of convex edges excluding those of external or internal tracks or grooves	5 mm	
Except within 150 mm from each **spar** end, the boom section shall be constant.		
Limit mark width	10 mm	
Outer point distance		2650 mm

C.14 SPINNAKER POLE

C.14.1 MATERIALS

(a) The **spar** shall be of aluminium alloy.

C.14.4 FITTINGS

(a) OPTIONAL

(1) A hook at each end.

(2) Fittings approximately at the mid-point for attachment for lift/downhaul.

(3) A fixed line between the fittings described in C.14.4 (a) (1), which may incorporate knots, toggles or short tubes for easier handling.

C.14.5 DIMENSIONS

	maximum
Spinnaker pole length	1900 mm

C.14.6 CONDITIONS FOR USE

(1) Only one spinnaker pole may be carried aboard.

C.15 STANDING RIGGING

C.15.1 MATERIALS

(a) The standing **rigging** shall be of stainless steel wire rope. Rod rigging is prohibited.

C.15.2 CONSTRUCTION

(a) MANDATORY

(1) A forestay of a diameter not less than 2.3 mm.

(2) Two shrouds of a diameter not less than 2.3 mm.

(3) The material of the trapeze line is optional, if wire rope is used it shall have a diameter not less than 2.3 mm. Each trapeze wire shall be provided with handholds, rings and adjustment. Self-tacking trapeze systems are not allowed.

(b) OPTIONAL

(1) Elastic cords on the trapeze wires approximately at the height of the spreaders.

(2) Shock-cord may be fitted between the forestay and the stemhead fitting, to maintain tension in the forestay.

C.15.3 FITTINGS

(a) MANDATORY

(1) Forestay attachment fittings.

(2) Each shroud shall be attached to the shroud plate by means of plates having rows of adjustment holes. No other arrangement of shroud adjustment is permitted.

C.15.4 CONDITIONS FOR USE

(1) The effective length of the shrouds shall not be adjusted when *racing*.

C.16 RUNNING RIGGING

C.16.1 MATERIALS

(a) Materials are optional except that Titanium is prohibited.

C.16.2 PARTS

(a) MANDATORY

(1) Mainsail halyard

(2) Headsail halyard

(3) Spinnaker halyard

(4) Spinnaker pole lift and downhaul

(b) OPTIONAL

(1) Mainsail Cunningham line

(2) Mainsail outhaul

C.16.3 FITTINGS

(a) OPTIONAL

(1) One block or eye in each headsail Barber hauler to run on headsail sheet

(2) One block or eye in each spinnaker Barber hauler to run on spinnaker sheet or guy.

C.16.4 CONDITIONS FOR USE

(1) **Sails** and sheets may be moved directly by hand without the use of a block.

C.17 SAILS

C.17.1 MODIFICATIONS AND MAINTENANCE

(a) Routine maintenance such as sewing, mending and patching is permitted without re-**certification**.

C.17.2 LIMITATIONS

(a) Not more than one mainsail, one jib and one spinnaker shall be carried aboard when *racing*.

(b) Not more than one mainsail, one jib and one spinnaker shall be used during an event, except when a **sail** has been lost or damaged beyond repair.

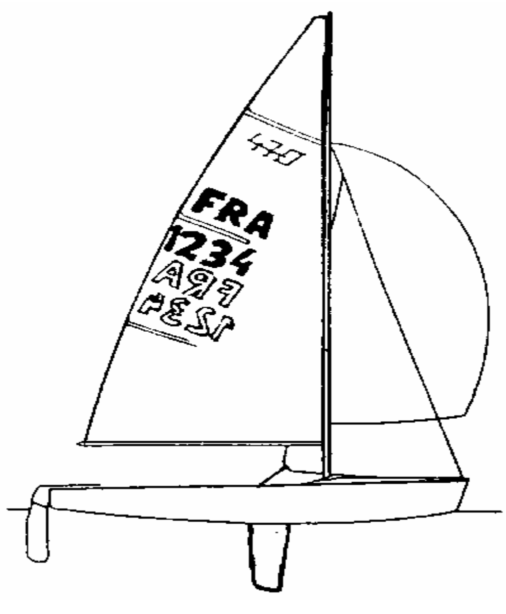
C.17.3 IDENTIFICATION

(a) The mainsail and spinnaker shall carry as sail identification the national letters and sail number. The sail number to be carried on the sails shall correspond to the last four digits of the official sail number issued according to A.10. The national letters and sail numbers size and position shall comply with the RRS except where otherwise prescribed in these class rules.

C.17.4 MAINSAIL

(a) IDENTIFICATION

(1) The sail identification shall be red, in paint or durable material, securely attached. It shall be placed as shown in the Figure "Sail Identification Location", and so that the characters on one side of the sail do not overlap with characters on the other side, leaving at least 60 mm in between.



Sail Identification Location

(2) Mainsails used in women's only events shall carry a red rhombus (length of diagonals minimum 240mm, maximum 260mm) above the top batten pocket on both sides. The position should be approximately in the centre of the triangle formed by the top batten and the mainsail head. The rhombus may be retained for racing in other events.

(3) The 470 mainsail insignia as per G.3.1 may be replaced by a gold version conforming to the same dimensions when at least one member of **crew** is an Olympic or World Champion.

(b) USE

(1) The **sail** shall be hoisted on a halyard. The arrangement shall permit hoisting and lowering of the **sail** at sea with the boat upright.

(2) **Luff** and foot bolt ropes shall be in the **spar** grooves or tracks.

(3) Battens shall be fitted, except in the case of accidental loss.

(4) The sail shall be set so that the highest visible point of it, projected at 90° to the mast spar, shall not be higher than the **upper point**; the aftmost visible part of the leech, projected at 90° to the boom, is forward of the **outer point** on the boom.

C.17.5 JIB

(a) USE

(1) The jib shall be hoisted and lowered on a halyard. The arrangement shall permit hoisting and lowering of the sail at sea with the **boat** upright.

(2) Only one luff wire of diameter not less than 2.3mm shall be fitted inside the jib luff sleeve.

C.17.6 SPINNAKER

(a) IDENTIFICATION

(1) Identification shall be of a contrasting colour to the body of the sail.

(2) As an alteration to RRS Appendix G, national letters may be positioned in line with the sail numbers.

Section D – Hull

D.1 GENERAL

D.1.1 RULES

(a) The **hull** shall comply with the **class rules** and official plans in force at the time of initial **certification,** but all fittings, **hull appendages** and **rig** shall comply with the current rules.

(b) For boats first **certified** after the 1st of March 1993, the hull shall be constructed in accordance with the Building Specification Plan and shall consist of the parts listed therein except where temporary alternatives have been approved for the builder by the ISAF in writing. All boats from any one builder shall be built to the same detailed specification submitted by the builder to ISAF.

D.1.2 CERTIFICATION

See Rule A.12.

D.1.3 DEFINITIONS

(a) HULL DATUM POINT

The **hull datum point** (HDP) is the projection of the AMP on the baseline.

(b) AFT MEASURING POINT

The aft measuring point (AMP) is the intersection on the hull centre plane of the transom external surface with the underside of the hull surface, both extended as necessary.

(c) FORWARD MEASURING POINT

The forward measuring point (FMP) is the **sheer** point on the stem, as shown in the Measurement References diagram.

(d) Unless otherwise stated, all measurements shall be taken parallel to the baseline.

D.1.4 IDENTIFICATION

(a) The **hull** shall carry the ISAF Plaque permanently attached to the starboard side tank close to the transom and bottom.

(b) The **hull** shall carry, either moulded in or on a plate, permanently fixed, the builder's mark, serial number and mould number, which also appear on the certificate. In addition, the builder's serial number shall be moulded on the outside of the transom on the starboard side.

D.1.5 BUILDERS

(a) The **hull** shall be built by a builder licensed by ISAF. **Hulls** shall be supplied only as permanently assembled boat units.

(b) All moulds shall be approved by ISAF.

(c) Application for a licence shall be made through a MNA to the ISAF. The licences shall include clauses requiring good standards of manufacture, compliance with class rules and plans and a guarantee that all fees shall be paid. The ISAF shall consult with 470 International before granting any licence and only sufficient licences will normally be issued in a country to ensure that demand is satisfied.

(d) Alteration to plugs or moulds made without the approval of the ISAF shall result in the builder's licence being revoked. This same measure shall be taken in case of intentional and/or repeated infringements of the class rules, by the builder.

D.1.6 MATERIALS

(a) Local reinforcement of GRP, wood, plywood or metal as backings for fittings may be added.

D.2 BUOYANCY TANKS

D.2.1 CONSTRUCTION

(a) Buoyancy equipment shall comprise of two foam buoyancy blocks located in the side tanks, one piece in each tank. The minimum volume is 0.05 m^3 each with a minimum length of 1500mm, according to the building specification.

D.3 ASSEMBLED HULL

D.3.1 FITTINGS

(a) MANDATORY

The following fittings shall be positioned in accordance with the Building Specifications unless otherwise noted:

(1) Stemhead fitting.

(2) Shroud plates.

(3) Mainsheet track and/or metal reinforcement, which shall be straight.

(4) Mast step, which may incorporate a means of fore and aft adjustment and which shall bear a mark 3055mm from the AMP engraved on the mast step or its mouldings. Additional dimensions for the mast step are mentioned in D.3.2.

(5) Two rudder fittings, which shall include a device to prevent the rudder becoming detached, bolted to the transom.

(b) OPTIONAL

(1) Jib and spinnaker halyard tensioning systems.

(2) An aft and/or centre mainsheet system may be used. Fittings and the adjustment system are optional, except that if a hoop is used, it shall be of aluminium and/or stainless steel.

(3) Mainsail Cunningham blocks, eyes, fairleads and cleats.

(4) Kicking strap adjustment.

(5) Headsail sheet blocks, fairleads and cleats.

(6) Headsail tack adjustment system, consisting of a shackle on the stemhead fitting, one cleat mounted on the foredeck, one fairlead behind the cleat and a single piece of rope.

(7) Fixed or adjustable jib sheet fairleads or pulleys. If traveller tracks are used, no more than one traveller car per track is permitted. Adjustment of the jib fairleads or pulleys may be remotely controlled only in one direction (e.g. fore/aft or in/out or up/down). Additional adjustments to the fairleads or pulleys are only permitted by means of prefixed positions.

(8) Spinnaker sheet and guy fairleads, blocks and cleats.

(9) Spinnaker sheet barber hauler fairleads, blocks and cleats.

(10) Spinnaker pole uphaul/downhaul fairleads, eyes, blocks and cleats.

(11) Toe straps fitted within the cockpit.

(12) Fittings for stowage of clips for paddle(s), spinnaker pole and other equipment

(13) Two self-bailers, with a total effective area not exceeding 12.5 $cm^{2.}$

(14) Spinnaker catcher device(s) which shall not project more than 150 mm beyond the bow or beyond the outboard edges of the gunwale.

(15) Sealing strips for the centreboard slot of optional material.

(16) Optional centreboard hoist system of pulleys, elastic cord and/or rope and cleats.

(17) Hinged covers or other devices for closing draining ports or drain holes in the transom. These covers or devices shall not obstruct the rudder or act as an extension of the bottom of the hull.

(18) A centreboard pivot including bush.

(19) Strips of a minimum length of 300mm to reduce friction and/or the distance between the centreboard and centreboard case, but no device shall be attached to the inside of the centreboard case that could cause the centreboard to gybe (angle to windward).

(20) Trapeze return system with elastic cord and blocks/fairleads.

(c) Fittings may be attached to brackets not exceeding 175mm x 125mm fixed to the side tanks.

(c) No fittings, with the exception of spinnaker sheet catcher(s), rudder fittings and transom drainage flaps shall project beyond the outboard edges of the gunwale rubbing strips or beyond the profile of the hull,

(d) No fitting shall serve as an extension of the hull surface.

(e) Control lines and/or sheets shall not pass through the buoyancy compartments or the breakwater.

(f) **Ballast** shall not be carried.

(g) Materials for permitted fittings are optional except that Titanium is prohibited.

D.3.2 DIMENSIONS

The keel line shall be taken as the intersection line from transom to stem of the hull shell and the hull centerplane.

The sections shall be taken as vertical, transverse planes at the following positions:

Section 1: at 500 mm from **hull datum point**.

Section 3: at 1500 mm from **hull datum point**.

Section 5: at 2500 mm from **hull datum point**.

Section 7: at 3500 mm from **hull datum point**.

Section 8: at 4000 mm from **hull datum point**.

The baseline shall be on the centerplane of the **hull** at the following vertical distances:

at the **hull datum point**: 230 mm from the AMP

at section 8 : 114 mm from the hull shell.

	minimum	maximum
Length of **hull** between AMP and FMP	4690 mm	4710 mm
Vertical distance from baseline to underside of hull shell;		
at section 1	174 mm	182 mm

at section 3 ....92 mm ....104 mm
at section 5 ....54 mm ....68 mm
at section 7 ....72 mm ....80 mm

Longitudinal distance from **hull datum point**
to centre of shroud plate holes: ....2770 mm .... 2790 mm

Fore and aft position of aft edge of the mast, projected
from above the sail entry at step level from **hull**
datum point…...3055 mm .... 3115 mm

Mast step bearing surface above the keelson
when fitted…… .... 5 mm

Mainsheet track and/or metal reinforcement shall be attached to the top of the
centerboard case and mounted at a distance from the
hull datum point of...1610 mm 1650mm

Inside diameter of buoyancy tank inspection holes ....110 mm .... 160 mm

Inside diameter of buoyancy tank draining holes ....10 mm .... 25 mm

D.3.3 WEIGHT

	minimum	maximum
Hull weight (refer to building specification)............................	86.0 kg	… kg

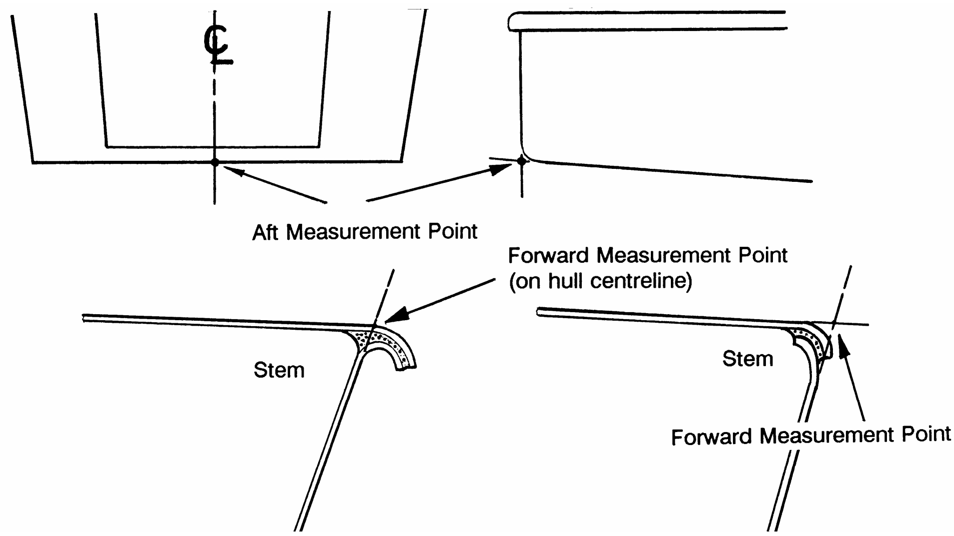
D.4 MEASUREMENT DIAGRAMS

Note:

(1) This part of the Class Rules makes reference to the Building Specification Plan.

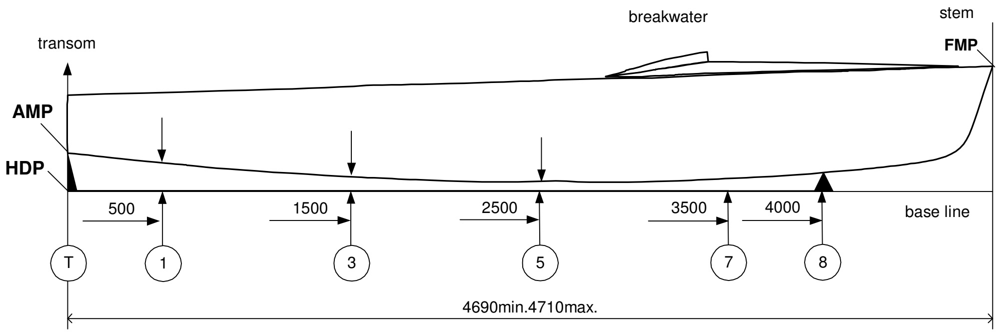
(2) Only templates supplied by ISAF shall be used for hull measurement.

D.4.1 HULL DATUM POINT



Measurement References

For measurement, the hull rests at a distance of 230 mm at the HDP and at a distance of 114 mm at Station 8 on the baseline, as Figure “Hull Measurement” shows.

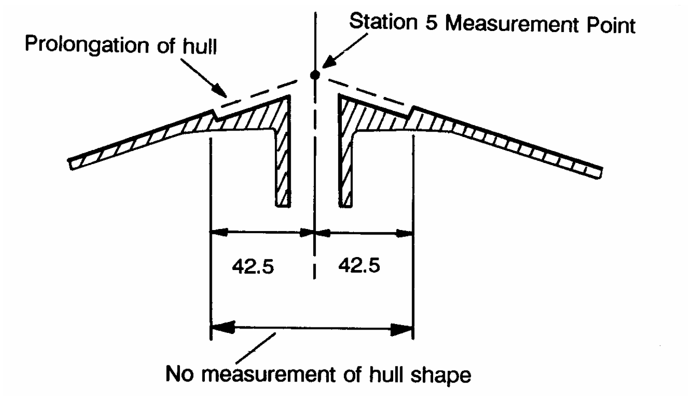


Hull Measurement

All measurements carried out from the **hull datum point** are parallel to the baseline.

The keel is measured at the following Stations: T, 1, 3, 5, 7, and 8 located on the baseline at 0 mm, 500mm, 1500mm, 2500mm, 3500mm and 4000mm respectively from the HDP.

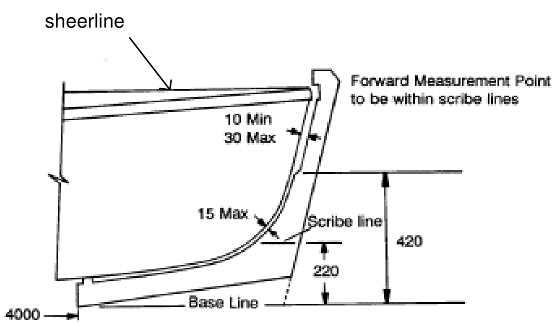
Since Station 5 corresponds to the middle of the centreboard box, the distance to the baseline is measured to the prolongation of the hull, as Figure "Section 5 measurement" shows.



Section 5 Measurement

D.4.2 STEM

The stem template shall be applied as shown on the measurement diagram

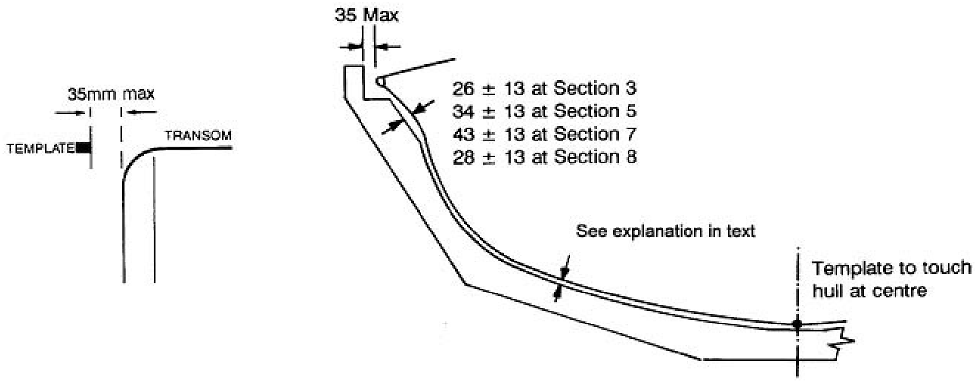


Between the sheerline and a point 420mm above the baseline the template shall clear by not less than 10mm nor more than 30mm.

Below the 420mm point the template shall touch lightly or clear by not more than 15mm.

D.4.3 ATHWARTSHIPS

Templates for the transom and section 1, 3, 5, 7 and 8 shall be applied as shown on the measurement diagram.



Hull Profile

The top of the deck at the sheerline shall not be more than 10mm above or below the sheer marks on the templates.

The templates shall touch the gunwale rubbing strakes lightly or clear by not more than 35mm. At the transom the distance to the template shall be defined as shown in the diagram.

Below the points 420mm above the baseline the clearance between the hull and the templates shall be between 5mm and 15mm at the transom and between 3mm and 17mm at sections 1, 3, 5, 7 and 8.

The difference between the maximum and minimum clearances shall not exceed 7mm at the transom and 10mm at the other sections.

Above the line 420mm above the baseline, the maximum distance of the surface of the hull from the templates shall be 26mm ± 13mm at section 3, 34mm ± 13mm at section 5, and 43mm ± 13mm at section 7.

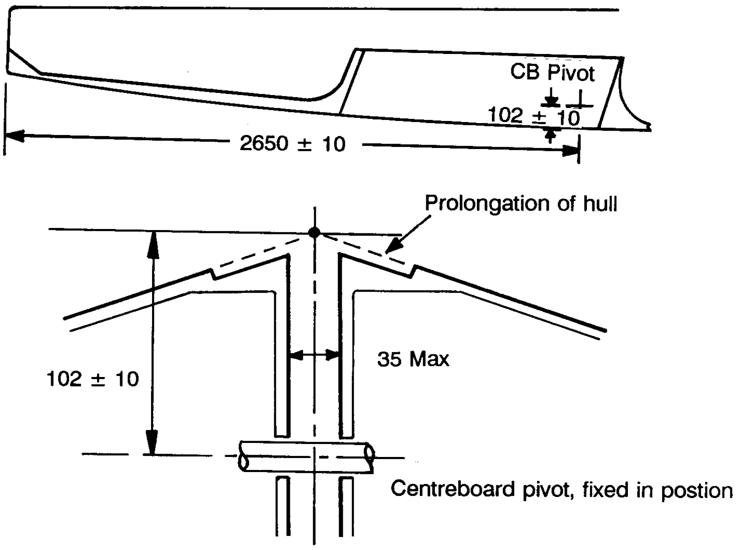
At section 8 from the template above the line 520mm above the baseline the maximum distance of the surface of the hull shall be 28mm ± 13mm.

The measurer shall test the surface of the hull with a flexible batten to ensure that the shape is fair.

D.4.4 CENTREBOARD PIVOT

The distance of the centre of the centreboard pivot from the HDP shall be 2650mm ± 10mm and its height above the baseline shall be 102mm ± 10mm.

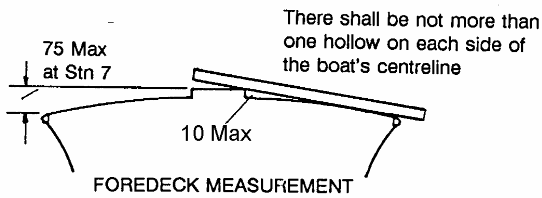
The pivot pin shall pass through the centreboard box and be in a fixed position.



Centreboard Pivot Position

D.4.5 FOREDECK

At section 7, the centre of the foredeck shall be not more than 75mm above the top of the deck at the sheerline.



Foredeck Measurement

A straight edge placed on the centreline of the foredeck shall be nowhere more than 5mm from the deck.

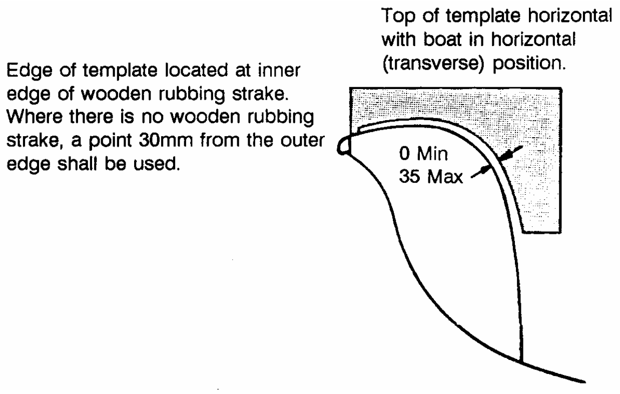
At the centreline the aft face of the breakwater shall be 3250mm ± 30mm forward of the HDP and at the sheer 2830mm ± 30mm.

D.4.6 SIDE TANKS

The shape of the side tanks surface above 280mm from the hull is measured by a template at Station 4.

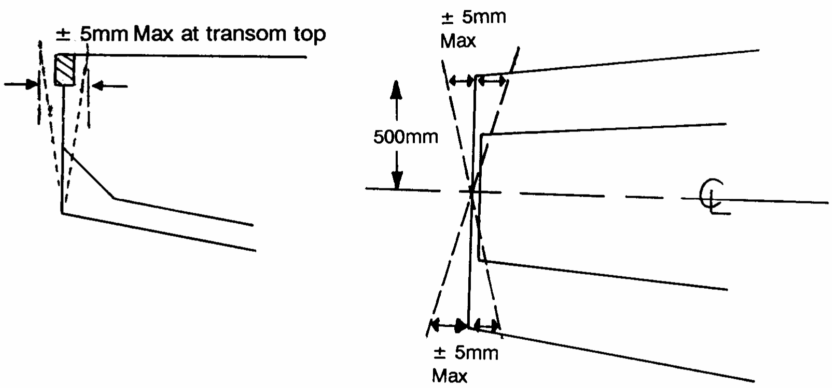
The template shall touch the tank lightly or clear by not more than 35mm.

The distance between the tanks (intersection with the hull shell) shall be verified at the transom (580mm), at Station 4 (830mm), and at Station 6 (770mm) with a tolerance of ± 30mm.



D.4.7 TRANSOM

The transom surface shall be perpendicular to the baseline, with the vertical and horizontal tolerances defined in the Figure "Transom tolerances".



Transom Tolerances

Section E – Hull Appendages

Not in use see Section C for hull appendage items

Section F – Rig

Not in use see Section C for rig items

Section G – Sails

G.1 PARTS

G.1.1 MANDATORY

(a) Mainsail

(b) Headsail

G.1.2 OPTIONAL

(a) Spinnaker

G.2 GENERAL

G.2.1 RULES

(a) **Sails** shall comply with the current **class rules**.

(b) Headsails may be measured with battens inside the **batten pockets**.

G.2.2 CERTIFICATION

(a) The **official measurer** shall **certify** mainsails and headsails in the **tack** and spinnakers in the **head** and shall sign and date the **certification mark**. Sails may be certified without identification on them.

(b) Sails shall carry the sail button/sticker issued by the ICA attesting that the class fee has been paid, and located for mainsails and headsails in the tack and spinnakers in the head.

(c) The ISAF or an MNA may appoint one or more **In-House Official Measurers** to measure and **certify sails** produced by that manufacturer.

G.2.3 SAILMAKER

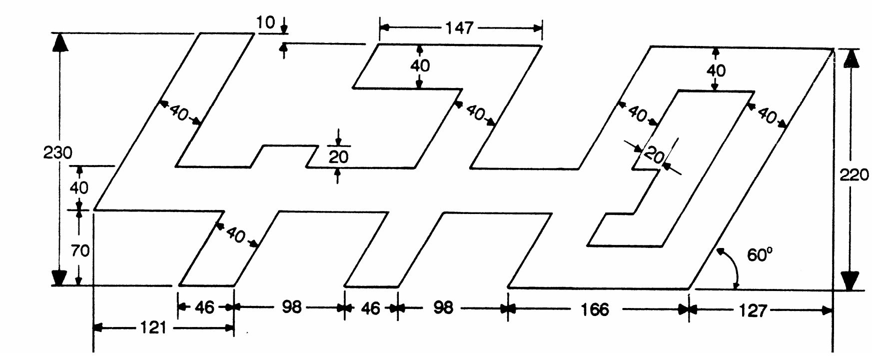
(a) The sailmaker is optional.

G.3 MAINSAIL

G.3.1 IDENTIFICATION

(a) The mainsail shall carry the 470 insignia in dark blue paint or other durable material, securely attached.

(b) The 470 insignia shall be placed under and in close proximity to the upper batten pocket and shall conform to the Figure "470 Emblem" with a tolerance of 2mm.



470 Insignia

G.3.2 MATERIALS

(a) The **ply** fibres shall be of polyester.

(b) Battens shall be made of any material.

G.3.3 CONSTRUCTION

(a) The construction shall be: **soft sail**, **single ply sail.**

(h) The **body of the sail** shall consist of the same white **woven ply** throughout except for the panel adjacent to the **foot,** which may be of a different white **woven ply.**

(i) The **sail** shall have three **batten pockets** in the **leech**.

(j) The **leech** shall not extend aft of straight lines between:

(1) the **aft head point** and the intersection of the **leech** and the upper edge of the nearest **batten pocket,**

(2) the intersection of the **leech** and the lower edge of a **batten pocket** and the intersection of the **leech** and the upper edge of an adjacent **batten pocket** below,

(3) the **clew point** and the intersection of the **leech** and the lower edge of the nearest **batten pocket**.

(e) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, headboard with fixings, Cunningham eye or pulley, **batten pocket patches** which may be made from a **woven ply** thinner than that of the body of the sail, batten pocket elastic, top batten pocket end cap at luff end and tensioning device at leech end, leech line with cleat on leech, not more than two **single ply windows**, one boom slide fixed at the **clew**, tell tales, sail shape indicator stripes, sail identification, sailmaker labels, sail button/sticker, **certification mark**.

G.3.4 DIMENSIONS

	minimum	maximum
Leech length		6265 mm
Quarter width		2340 mm
Half width		1790 mm
Three-quarter width		1050 mm
Top width		140 mm
Thickness of **ply** of the **body of the sail**	0.165 mm	
Primary reinforcement		325 mm
Secondary reinforcement:		
from **sail corner measurement points**		1000 mm
from the **leech**		300 mm
area above top batten pocket		unlimited
Distance from **clew point** to **foot** bolt rope		60 mm
Distance from **tack point** to **foot** bolt rope		300 mm
Total area of **Windows**		0.3 m^2
Window to **sail edge**	150 mm	
Extension of headboard from **head point**		140 mm
Batten pocket inside length: (Intermediate and lowermost pockets)		800 mm
Intersection of a batten pocket centreline and leech to adjacent cross width measurement point		100 mm

	minimum	maximum
Head point to intersection of **luff** and centreline of uppermost **batten pocket** when the luff is under sufficient tension to remove wrinkles	1680 mm	1780 mm

G.4 HEADSAIL

G.4.1 MATERIALS

(a) The **ply** fibres shall be of polyester.

(b) Battens shall be made any material

G.4.2 CONSTRUCTION

(a) The construction shall be: **soft sail**, **single ply sail**.

(b) The **body of the sail** shall consist of the same white **woven ply** throughout.

(c) The headsail shall have a maximum of three **batten pockets** in the **leech**.

(d) The **leech** shall not extend beyond a straight line from the aft **head point** to the **clew point**.

(e) The following are permitted: Stitching, glues, tapes, tabling, corner eyes, **flutter patches**, **batten pocket patches** which may be made from a **woven ply** thinner than that of the body of the sail, not more than two **single ply windows**, tell tales, sail shape indicator stripes, sail identification, sailmaker labels, sail button/sticker, **certification mark**.

G.4.3 DIMENSIONS

	minimum	maximum
Luff length		4100 mm
Leech length		3750 mm
Foot length		1955 mm
Foot median		3950 mm
Top width		30 mm
Foot irregularity		30 mm
Thickness of **ply** of the **body of the sail**	0.165 mm	
Primary reinforcement		275 mm
Secondary reinforcement:		
from **sail corner measurement points**		750 mm
for 1 **chafing patch** on the **luff**		
along the **luff**		300 mm
perpendicular to the **luff**		50 mm
Total area of **Windows**		0.3 m^2
Window to **sail edge**	150 mm	
Batten pocket inside length:		250 mm

G.5 SPINNAKER

G.5.1 MATERIALS

(a) The **ply** fibres shall be of polyester or nylon.

G.5.2 CONSTRUCTION

(a) The construction shall be: **soft sail**, **single ply sail**.

(b) The **body of the sail** shall consist of the same **woven ply** material throughout.

(c) The following are permitted: Stitching, glues, tapes, corner eyes, tape eyes, tell tales, sail shape indicator stripes, sail identification, sailmaker labels, sail button/sticker, **certification mark**.

G.5.4 DIMENSIONS

	minimum	maximum
Leech lengths		4360 mm
Foot length		3000 mm
Foot Median		5100 mm
Difference between **diagonals**		50 mm
Upper width (**upper leech points** at 200 mm from **head point**)		350 mm
Half width		3450 mm
Three-quarter width		1830 mm
Primary reinforcement		300 mm
Secondary reinforcement		unlimited

<u>OFFICIAL PLANS</u>

1	Building Specification Plan	2009
2	Lines Plan	1964
3	Class Emblem (Full size)	1992
4	Full Size Sections	1964
5	Full Size Sections	1964
6	Full Size detail of Stem	1964

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Section G - Sails

G.1 PARTS

G.1.1 MANDATORY

(a) Mainsail

(b) Headsail

G.1.2 OPTIONAL

(a) Spinnaker

G.2 GENERAL

G.2.1 RULES

(a) **Sails** shall comply with the current **class rules**.

(b) Headsails may be measured with battens inside the **batten pockets**.

G.2.2 CERTIFICATION

(a) The **official measurer** shall **certify** mainsails and headsails in the **tack** and spinnakers in the **head** and shall sign and date the **certification mark**. Sails may be certified without identification on them.

(b) Sails shall carry the sail sticker issued by the ICA attesting that the class fee has been paid, and located for mainsails and headsails in the tack and spinnakers in the head.

(c) The ISAF or an MNA may appoint one or more **In-house Official Measurers** to measure and **certify sails** produced by that manufacturer.

(d) Not more than 3 sails for year can be certificated by a sailor. In case of doing 6 or more events from the ISAF Sailing World Cup and the worlds the limit will rise up to 4 sails for each sailor. The sailors shall be ICA members.

G.2.3 SAILMAKER

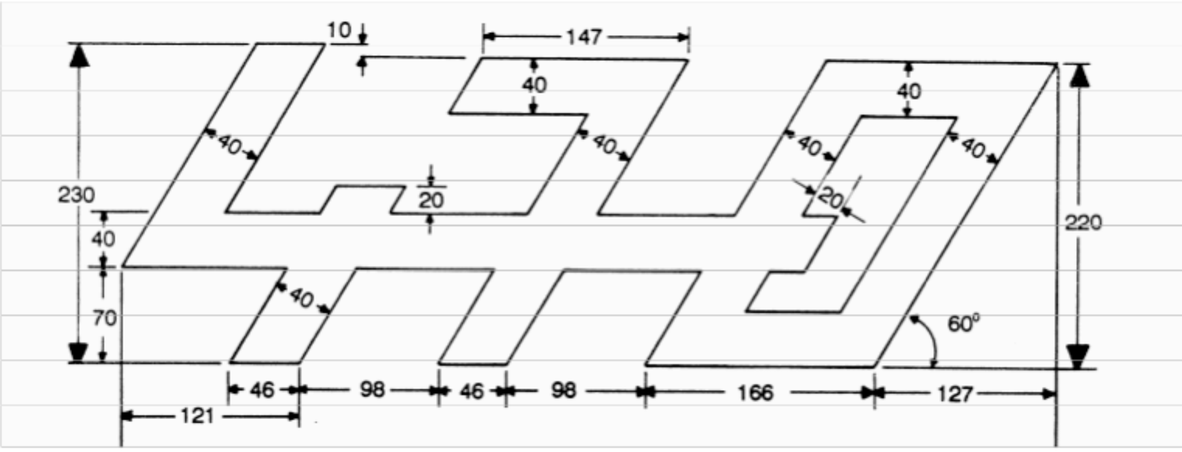
(a) The sailmaker is optional.

G.3 MAINSAIL

G.3.1 IDENTIFICATION

(a) The mainsail shall carry the 470 insignia in gold paint or other durable material, securely attached. People who have sailed an Olympics could attached the Olympic rings behind the insignia.

(b) The 470 insignia shall be placed under and in proximity to the upper batten pocket and shall conform to the Figure "470 Emblem" with a tolerance of 2 mm.



470 Insignia

G.3.2 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.3.3 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The **sail** shall have four **batten pockets** in the **leech.**

(c) The **leech** shall not extend aft of straight lines between:

(1) The **aft head point** and the intersection of the **leech** and the upper edge of the nearest **batten pocket,**

(2) the intersection of the **leech** and the lower edge of a **batten pocket** and the intersection of the **leech** and the upper edge of an adjacent **batten pocket** below,

(3) the **clew point** and the intersection of the **leech** and the lower edge of the nearest **batten pocket.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, headboard with fixings, cunningham eye or pulley, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** boom slide fixed at the **clew,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.3.4 DIMENSIONS

	minimum	maximum
Leech length		6000 mm
Quarter width		2000 mm
Half width		1900 mm
Three-quarter width		1800 mm
Top width		1400 mm
Foot length		2100 mm
Thickness of the **body of the sail**	0.165 mm	
Distance from **clew point** to **foot** bolt rope		60 mm
Distance from **tack point** to **foot** bolt rope		300 mm
Window to **sail edge**	150 mm	
Weight	2.5 kg	

G.4 HEADSAIL

G.4.1 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.4.2 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The headsail shall have a maximum of three **batten pockets** in the leech.

(c) The **leech** shall not extend beyond a straight from the aft **head point** to the aft of the first **batten pocket** and from the aft of the first **batten pocket** to the **clew point.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.4.3 DIMENSIONS

	minimum	maximum
Luff length		4500 mm
Leech length from the head sail to the first aft point of the batten pocket		340 mm
Leech length from the aft point of the batten pocket to the clew		3910 mm
Foot length		2200 mm
Foot median		4300 mm
First batten width		180 mm
Top width		30 mm
Foot irregularity		30 mm
Weight	0.9 kg	

G.5 SPINNAKER

G.5. MATERIALS

(a) The fibres shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

G.5.1 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The following are permitted: Stitching, glues, tapes, corner eyes, tape eyes, tell tales, sail shape indicator stripes, sail identification, sail-maker labels, sail sticker, **certification mark.**

G.5.4 DIMENSIONS

	minimum	maximum
Luff lengths		4660 mm
Foot length		3000 mm
Foot median		5100 mm
Difference between diagonals		50 mm
Upper width (upper leech points at 200 mm from head point)		350 mm
Half width		3450 mm
Three-quarter width		1830 mm
Weight	0.6 kg	

Section G - Sails

G.1 PARTS

G.1.1 MANDATORY

(a) Mainsail

(b) Headsail

G.1.2 OPTIONAL

(a) Spinnaker

G.2 GENERAL

G.2.1 RULES

(a) **Sails** shall comply with the current **class rules**.

(b) Headsails may be measured with battens inside the **batten pockets**.

G.2.2 CERTIFICATION

(a) The **official measurer** shall **certify** mainsails and headsails in the **tack** and spinnakers in the **head** and shall sign and date the **certification mark**. Sails may be certified without identification on them.

(b) Sails shall carry the sail sticker issued by the ICA attesting that the class fee has been paid, and located for mainsails and headsails in the tack and spinnakers in the head.

(c) The ISAF or an MNA may appoint one or more **In-house Official Measurers** to measure and **certify sails** produced by that manufacturer.

(d) Not more than 3 sails for year can be certificated by a sailor. In case of doing 6 or more events from the ISAF Sailing World Cup and the worlds the limit will rise up to 4 sails for each sailor. The sailors shall be ICA members.

G.2.3 SAILMAKER

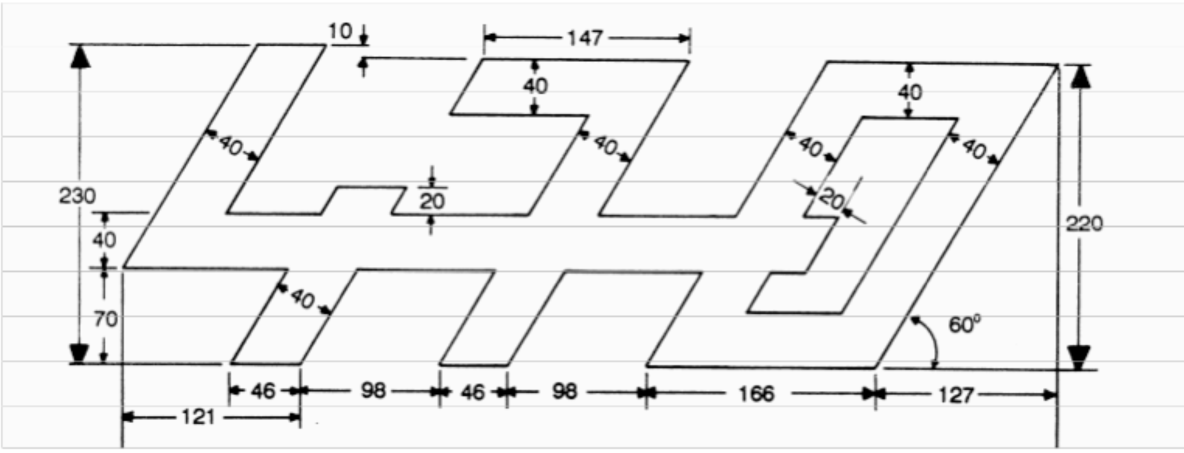
(a) The sailmaker is optional.

G.3 MAINSAIL

G.3.1 IDENTIFICATION

(a) The mainsail shall carry the 470 insignia in gold paint or other durable material, securely attached. People who have sailed an Olympics could attached the Olympic rings behind the insignia.

(b) The 470 insignia shall be placed under and in proximity to the upper batten pocket and shall conform to the Figure "470 Emblem" with a tolerance of 2 mm.



470 Insignia

G.3.2 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.3.3 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The **sail** shall have six **batten pockets** in the **leech.**

(c) The **leech** shall not extend aft of straight lines between:

(1) The **aft head point** and the intersection of the **leech** and the upper edge of the nearest **batten pocket,**

(2) the intersection of the **leech** and the lower edge of a **batten pocket** and the intersection of the **leech** and the upper edge of an adjacent **batten pocket** below,

(3) the **clew point** and the intersection of the **leech** and the lower edge of the nearest **batten pocket.**

(d) A reefing system reducing maximum 25% of the luff length of the sail. It can be done or undonev just once while racing.

(e) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, headboard with fixings, cunningham eye or pulley, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** boom slide fixed at the **clew,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.3.4 DIMENSIONS

	minimum	maximum
Leech length		7000 mm
Quarter width		2480 mm
Half width		2200 mm
Three-quarter width		1900 mm
Top width		1500 mm
Foot length		2650 mm
Thickness of the **body of the sail**	0.165 mm	
Distance from **clew point** to **foot** bolt rope		60 mm
Distance from **tack point** to **foot** bolt rope		300 mm
Window to **sail edge**	150 mm	
Weight	3 kg	

G.4 HEADSAIL

G.4.1 MATERIALS

(a) The **ply** fibers shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

(c) Battens shall be made of any material.

(d) All the seams and finishes shall be red.

G.4.2 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The headsail shall have a maximum of four **batten pockets** in the leech.

(c) The **leech** shall not extend beyond a straight from the aft **head point** to the aft of the first **batten pocket** and from the aft of the first **batten pocket** to the **clew point.**

(d) The following are permitted: Stitching, glues, tapes, bolt ropes, corner eyes, **batten pocket patches**, batten pocket elastic, batten pocket end cap at luff end and tensioning device, leech line with cleat on the leech, **single ply windows,** tell tales, sail shape indicator stripes, sail identification, sail-marker labels, sail sticker, **certification mark.**

G.4.3 DIMENSIONS

	minimum	maximum
Luff length		5200 mm
Leech length		4900 mm
Foot length		2000 mm
Foot median		5000 mm
Top width		170 mm
Foot irregularity		30 mm
Weight	1 kg	

G.5 SPINNAKER

G.5. MATERIALS

(a) The fibres shall be of any material.

(b) The cloth weight cannot differ more than 20% between areas.

G.5.1 CONSTRUCTION

(a) The construction shall be: **soft sail, single ply sail.**

(b) The following are permitted: Stitching, glues, tapes, corner eyes, tape eyes, tell tales, sail shape indicator stripes, sail identification, sail-maker labels, sail sticker, **certification mark.**

G.5.4 DIMENSIONS

	minimum	maximum
Luff lengths		7000 mm
Foot length		5000 mm
Foot median		8600 mm
Difference between diagonals		50 mm
Half width		5600 mm
Weight	0.9 kg	

V3 Rig Rules

C.11 RIG

C.11.1 LIMITATIONS

(a) Only one mast, boom and spinnaker pole shall be used during an event except when an item has been lost or damaged beyond repair.

C.11.2 DEFINITIONS

(a) MAST DATUM POINT

The **mast datum point** (MDP) is the **heel point**. Unless indicated otherwise, all measurements are from the MDP-

C.11.3 MANUFACTURER

(a) **Spar** manufacturer is optional.

C.12 MAST

C.12.1 MATERIALS

(a) The **spar** shall be of carbon. Titanium or carbon are not allowed for fittings. Differences in laminated thickness are not allowed in a mast part.

C.12.2 CONSTRUCTION

(a) The **spar** shall include a fixed sail groove or track, which shall not be integral with the **spar.** The **spar** shall be round.

(b) The **spar** is composed of 3 parts of length defined in C.12.4

C.12.3 FITTINGS

(a) MANDATORY

(1) A gooseneck.

(2) Kicking strap attachment.

(3) Spinnaker pole fitting.

(4) Spinnaker pole downhaul blocks and/or sheave boxes with attachment.

(5) Spinnaker pole lift blocks and/or sheave boxes with attachment.

(6) Four fixed or adjustable metal **spreaders** with optional attachment systems which may include local reinforcement according to C.12.4

(7) Headsail halyard block(s) and or sheave box(es).

(8) Attachments for shrouds, forestay and trapezes.

(9) Spinnaker halyard blocks and/or sheave boxes.

(10) A sheave or sheave box and a rack lock or cleat for the mainsail halyard.

(11) A device to ensure compliance with ERS B.9.1 (a) if the mainsail halyard system itself does not do so.

(12) Permanently painted/taped **limit marks.**

(b) OPTIONAL

(1) A heel fitting.

(2) A fitting for centreboard hoist blocks.

(3) Mainsail halyard blocks and/or sheave boxes.

(4) Headsail halyard cleat.

(5) Fitting(s) for cunningham adjustment.

(6) Reinforcement at mast partner according to C.12.4.

(7) A removable timing device.

(8) Attachment fittings for removable compass.

(9) A fitting to attach mainsail **tack** to **spar.**

(10) Devices attached to the **spreaders** to prevent the spinnaker halyard form getting tangled.

(11) A masthead fittings which may include a mainsail halyard sheave.

(12) One mechanical wind indicator.

(13) Fittings for the lower spreader regulation system.

C.12.4 DIMENSIONS

	minimum	maximum
Mast spar permanent bend **fore-and-aft**		40 mm
Mast spar section between MDP and 5950 mm	55 mm	58 mm
Mast spar section between 5950 mm and top	60 mm	62 mm
Mast limit mark width	10 mm	
Lower point height		1055 mm
Upper point to the **lower point**		7750 mm
Forestay height	6480 mm	6500 mm
Trapeze height	8605 mm	8655 mm
Shroud height	8555 mm	8605 mm
Diagonal **shroud height**	6520 mm	6570 mm
Lower part lenght	2170 mm	2175 mm
Middle part lenght	3770 mm	3775 mm
Top part lenght	2880 mm	2885 mm
Overall lenght	8800 mm	8805 mm
Overlap between parts	250 mm	
Spinnaker pole fitting:		
height	1240 mm	1260 mm
projection		40 mm
Spinnaker hoist height		8505 mm
Lower spreader height	4200 mm	4300 mm
Higher spreader height	7400 mm	7500 mm
Jib halyard height	6380 mm	6420 mm
Distance between the aft face of the mast and the gooseneck pivot		35 mm

C.12.5 WEIGHTS

The weight of the **mast** includes rigging specified under C.15.2; C.15.3 (a) (1); C.16.2 (a), fittings specified under C.12.3 and permanently fastened compass bracket if applicable, but without wind indicator, compass and/or timing device:

	minimum	maximum
Mast weight	6 kg	
Mast corrector weights		0.2 Kg

Corrector weights shall be permanently fastened so that no part of the corrector is more than 200 mm from the **upper point.**

C.12.6 CONDITIONS FOR USE

(a) USE

(1) The fore and aft bend of the mast **spar** may be controlled at the mast partner by one of the following devices:

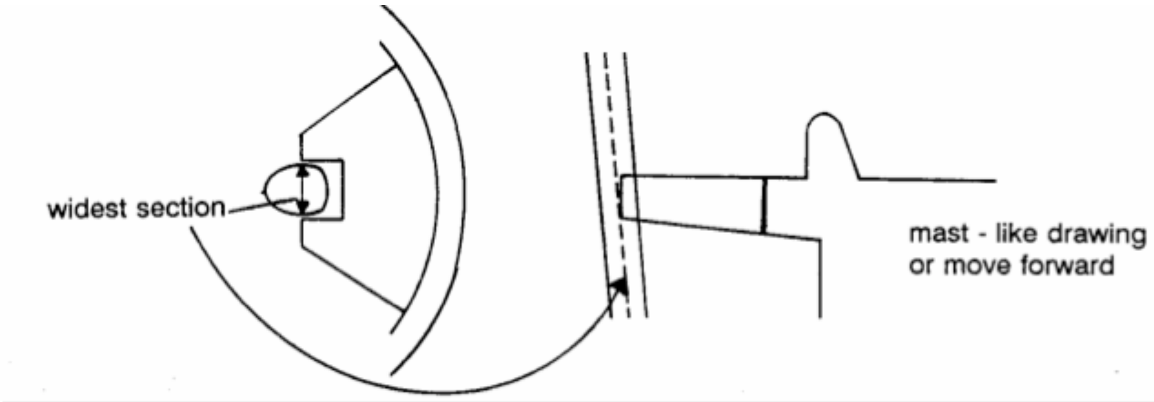
(i) Chocks between the mast **spar** and the mast partner (forward of the mast).

(ii) Optional systems of ropes or wires which may include attachments, blocks, levers, grips and cleats, all located on top of the mast partner.

(2) The sideways play between the mast **spar** and the mast partner may be controlled by strips of any material permanently fastened to the mast partner.

(3) The mast heel position shall not be adjusted while racing.

(4) The forestay under tension shall be entirely in metal and shall prevent the mast from disengaging from the mast partners. To meet this requirement the widest section of the mast shall be within the mast partners when the mast rakes under its own weight and the forestay comes under tension, as Figure “Mast Rake with Tensioned Forestay” shows:



Mast Rake with Tensioned Forestay

(5) Adjustable spreaders if used; the down spreaders may be remotely controlled, and may be adjusted when racing and top spreaders shall not be remotely controlled, and shall not be adjusted when racing.

C.13 BOOM

C.13.1 MATERIALS

(a) The boom **spar** shall be of aluminium alloy.

C.13.2 CONSTRUCCION

(a) The **boom** shall include a fixed aluminium sail groove or track which may or may not be integral with the **spar**.

C.13.3 FITTINGS

(a) MANDATORY

(1) A gooseneck attachment.

(2) A kicking strap fitting.

(3) Main sheet block(s) with attachment fittings(s) for the blocks and/or mainsheet which may be adjustable.

(4) Mainsail **clew** outhaul attachment or adjustment system.

(5) A stopper to ensure compliance with C.17.4.(b).(4).

(6) Permanently painted / taped **limit mark**.

(b) OPTIONAL

(1) A fitting to attach mainsail **tack**.

(2) An aft **spar** end fitting.

(3) The **spar** may be protected in the area where it touches the shrouds by pieces of any material, with maximum length / height / thickness = 100/50/5 mm.

C.13.4 DIMENSIONS

	minimum	maximum
Boom spar deflection when laded with 80Kg at a point midway between points 100 mm from each end and with the groove uppermost:		
vertical		50 mm
Boom spar cross section		
vertical	54 mm	72 mm
transverse	38 mm	
Radius of convex edges excluding those of external or internal tracks or grooves	5 mm	
Except within 150 mm from each **spar** end, the boom section shall be constant.		
Limit mark width	10 mm	
Outer point distance		2650 mm

C.14 SPINNAKER POLE

C.14.1 MATERIALS

(a) The **spar** shall be of aluminium alloy.

C.14.2 FITTINGS

(a) A hook at each end.

(b) Fittings approximately at the mid-point for attachment for lift/downhaul.

(c) A fixed line between the fittings described in C.14.2 (a), which may incorporate knots, toggles or short tubes for easier handling.

C.14.3 DIMENSIONS

	maximum
Spinnaker pole length	2200 mm

C.14.4 CONDITIONS FOR USE

(a) Only one spinnaker pole may be carried aboard.

(b) The spinnaker pole shall float in the water at least 15min.

C.15 STANDING RIGGING

C.15.1 MATERIALS

(a) The standing rigging shall be of stainless steel wire rope. Rod rigging is prohibited.

C.15.2 CONSTRUCTION

(a) MANDATORY

(1) A forestay of a diameter not less than 2.3 mm.

(2) Two shrouds of a diameter not less than 2.3 mm

(3) The material of the trapeze line is optional, if wire is used it shall have a diameter not less than 2.3 mm. Each trapeze wire shall be provided with handholds, rings and adjustment. Self-tacking trapeze systems are not allowed.

(b) OPTIONAL

(1) Elastic cords on the trapeze wires approximately at the height of the spreaders.

(2) Shock - cord may be fitted between the forestay and the stem head fitting to maintain tension in the forestay.

C.15.3 FITTINGS

(a) Forestay attachment fittings.

(b) Each shroud shall be attached to the shroud plate by means of plates having row of adjustment holes. No other arrangement of shroud adjustment is permitted.

C.15.4 CONDITIONS FOR USE

(a) The effective length of the shrouds shall not be adjusted when racing.

C.16 RUNNING RIGGING

C.16.1 MATERIALS

(a) Materials are optional except that Titanium is prohibited.

C.16.2 PARTS

(a) MANDATORY

(1) Mainsail halyard.

(2) Headsail halyard.

(3) Spinnaker halyard.

(4) Spinnaker pole lift and downhaul.

(b) OPTIONAL

(1) Mainsail Cunningham line.

(2) Mainsail outhaul.

(3) Mainsail reef system.

C.16.3 FITTINGS

(a) OPTIONAL

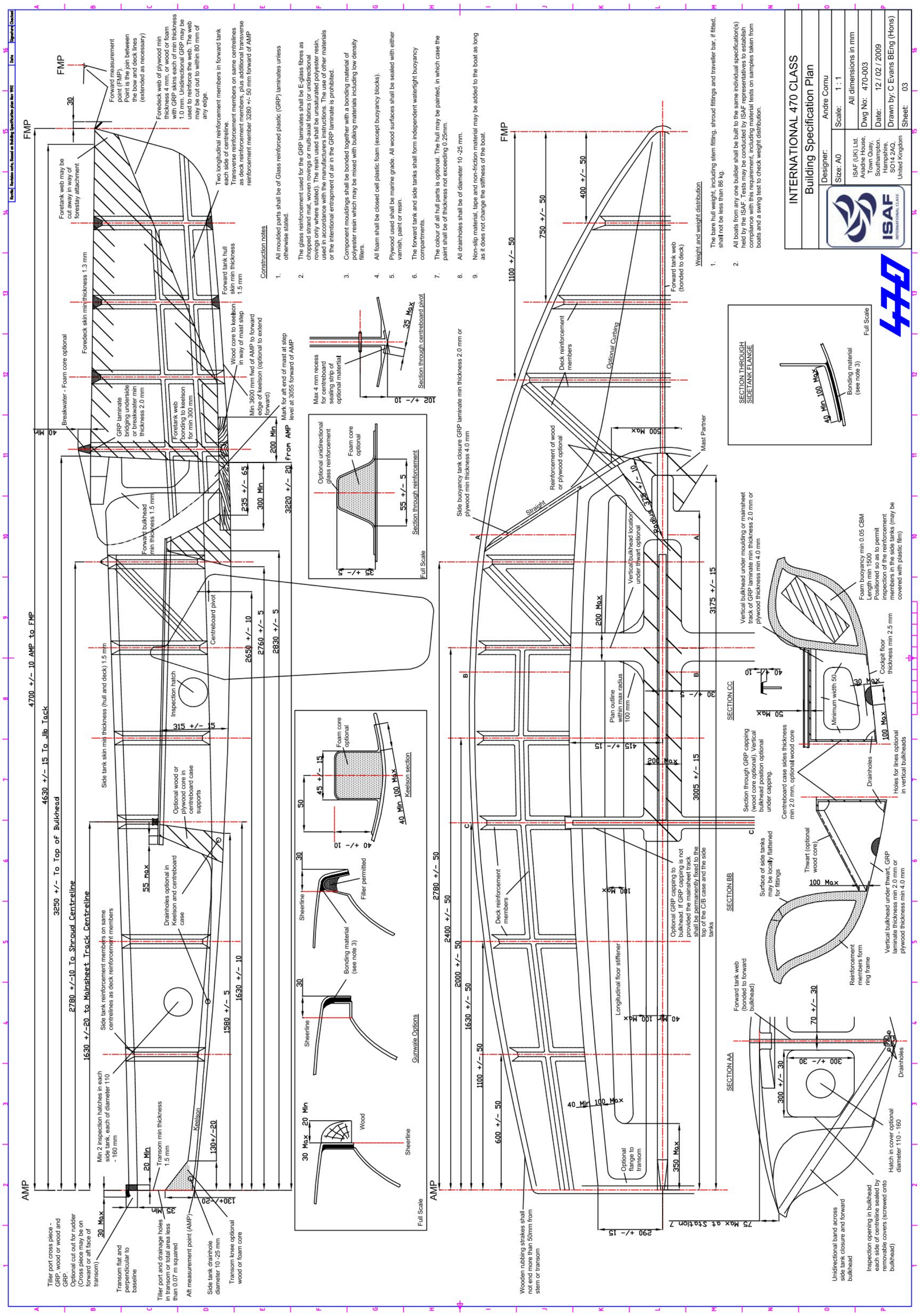
(1) One block or eye in each head sail Barber hauler to run on spinnaker sheet or guy.

C.16.4 CONDITIONS FOR USE

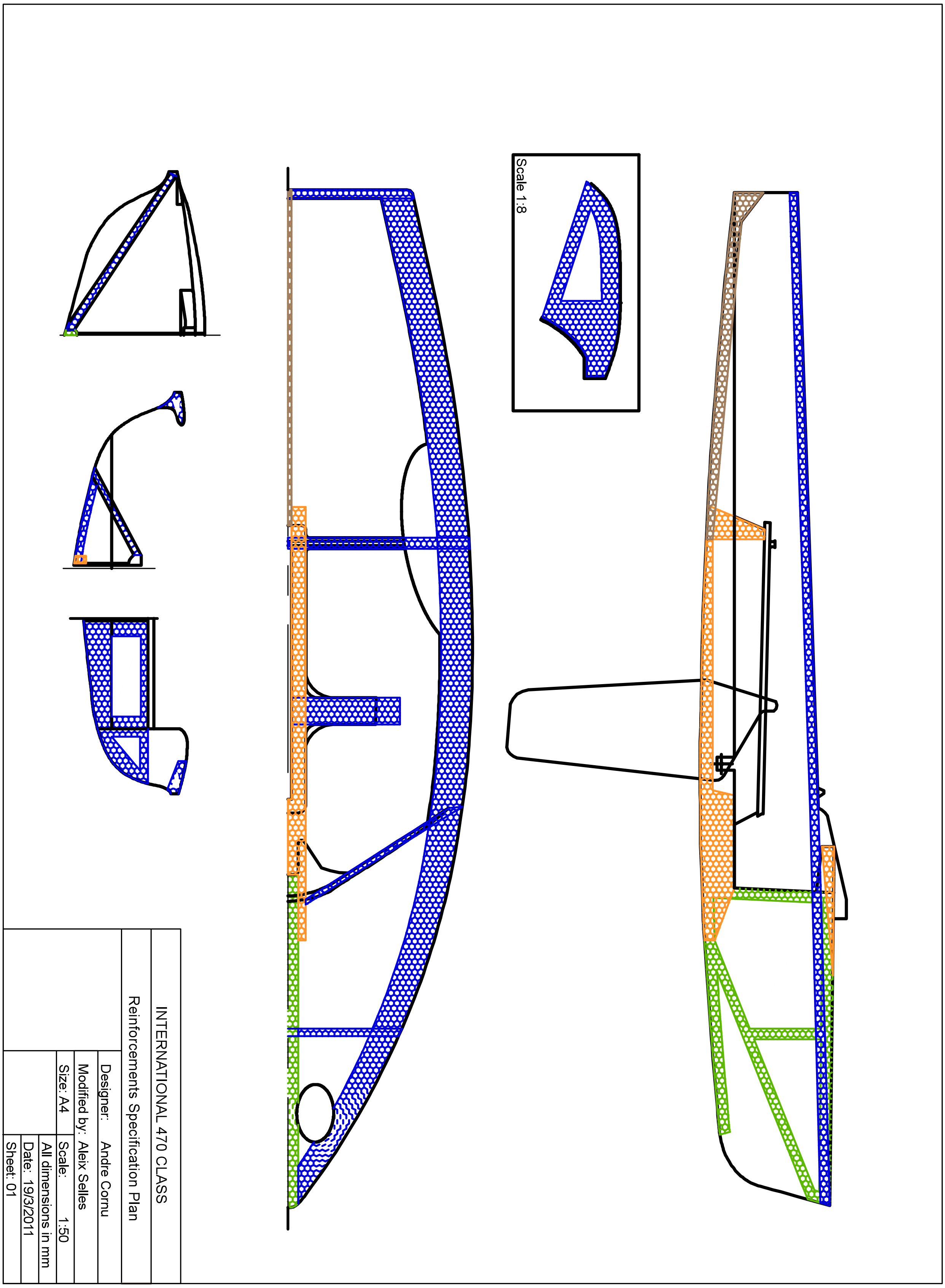
(1) **Sails** and sheets may be move directly by hand without the use of a block.

Appendix 2

Current 470 Building Plan



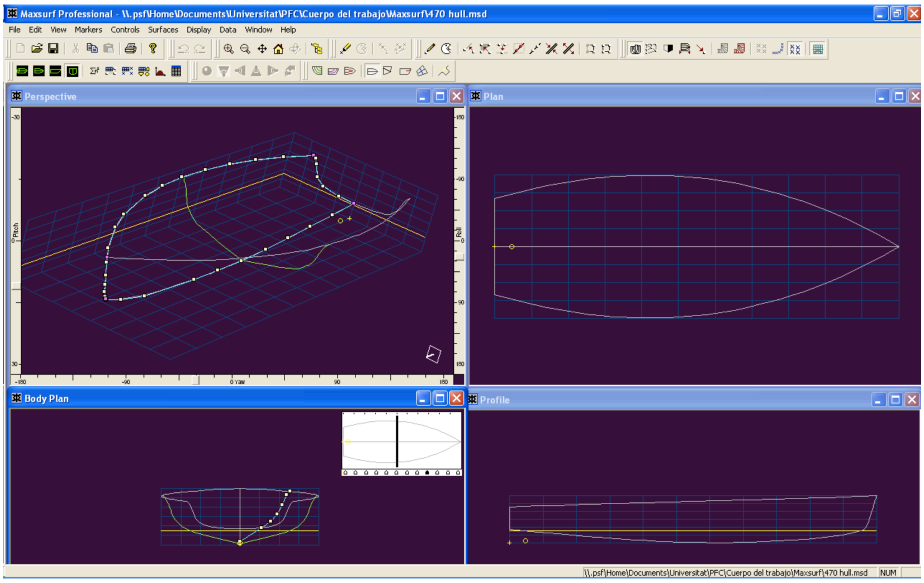
<u>New 470 Reinforcements Specification Plan</u>



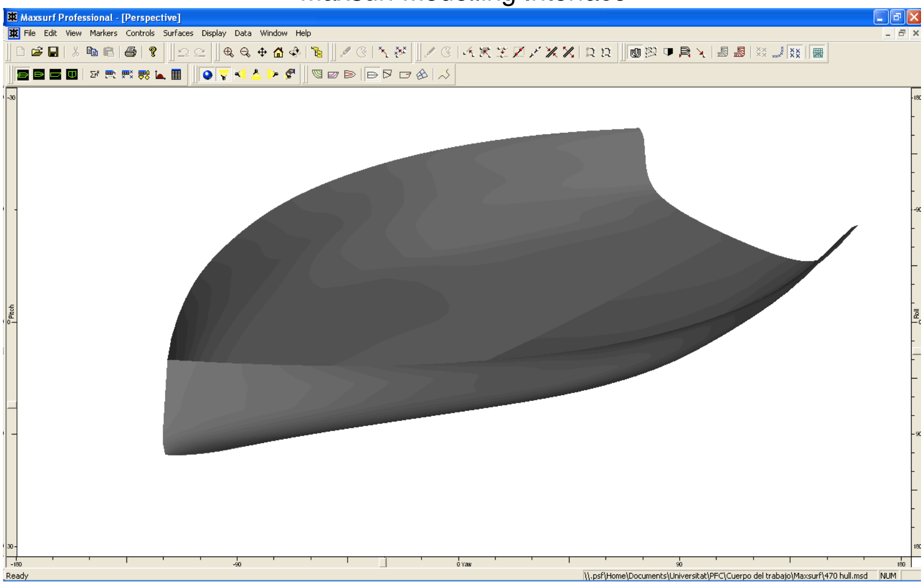
Appendix 3 CFD Chart

Sailplan	Method	Speed	Cl	Cd	Clmain	Cdmain	Cljib	Cdjib	Fx	Fy
Standard	Fiddes	5	1,135	0,200	1,131	0,289	1,146	0,027	50,87	230,74
Standard	Fiddes	8	1,137	0,201	1,132	0,290	1,149	0,028	130,83	592,43
Standard	Fiddes	12	1,137	0,201	1,132	0,276	1,148	0,028	293,91	1331,67
Standard	Fiddes	16	1,136	0,201	1,311	0,289	1,147	0,027	522,32	2368,01
Standard	K & P	5	1,323	0,200	1,365	0,210	1,223	0,176	67,92	265,27
Standard	K & P	8	1,327	0,201	1,366	0,211	1,225	0,177	697,82	2722,75
Standard	K & P	12	1,326	0,201	1,367	0,211	1,227	0,177	392,98	1531,41
Standard	K & P	16	1,324	0,201	1,368	0,211	1,228	0,178	175,04	681,42
V1	Fiddes	5	1,242	0,095	1,282	0,043	1,355	0,202	104,43	306,41
V1	Fiddes	8	1,267	0,033	1,311	-0,052	1,384	0,209	284,63	712,17
V1	Fiddes	12	1,246	0,086	1,287	0,029	1,360	0,203	617,71	1767,32
V1	Fiddes	16	1,243	0,091	1,284	0,037	1,357	0,203	1082,85	3143,82
V1	K & P	5	1,306	0,095	1,204	0,244	1,324	0,029	824,70	3075,35
V1	K & P	8	1,335	0,033	1,203	0,244	1,322	0,029	80,17	299,44
V1	K & P	12	1,311	0,086	1,228	0,246	1,348	0,032	193,75	708,65
V1	K & P	16	1,308	0,091	1,207	0,244	1,327	0,030	465,27	1731,26
V3	Fiddes	5	1,387	0,222	1,349	0,357	1,492	0,057	101,46	489,86
V3	Fiddes	8	1,387	0,222	1,351	0,357	1,497	0,057	589,17	2828,46
V3	Fiddes	12	1,390	0,216	1,480	0,216	1,655	0,238	138,37	527,67
V3	Fiddes	16	1,389	0,220	1,480	0,216	1,655	0,238	354,22	1350,83
V3	K & P	5	1,527	0,222	1,483	0,208	1,660	0,239	813,86	3043,88
V3	K & P	8	1,527	0,222	1,481	0,213	1,657	0,239	1431,43	5414,26
V3	K & P	12	1,531	0,216	1,349	0,357	1,492	0,057	259,73	1254,03
V3	K & P	16	1,528	0,220	1,350	0,357	1,494	0,057	1043,46	5028,13
V3 with reef	Fiddes	5	1,244	0,228	1,152	0,329	1,420	0,069	73,24	342,67
V3 with reef	Fiddes	8	1,244	0,228	1,152	0,329	1,420	0,069	187,49	877,23
V3 with reef	Fiddes	12	1,245	0,228	1,175	0,231	1,570	0,222	83,44	358,20
V3 with reef	Fiddes	16	1,245	0,228	1,176	0,231	1,573	0,223	482,87	2067,84
V3 with reef	K & P	5	1,310	0,228	1,153	0,330	1,423	0,070	423,05	1977,23
V3 with reef	K & P	8	1,310	0,228	1,153	0,329	1,421	0,070	751,89	3516,34
V3 with reef	K & P	12	1,312	0,228	1,175	0,231	1,571	0,223	857,30	3676,47
V3 with reef	K & P	16	1,311	0,228	1,175	0,231	1,570	0,222	213,60	916,98

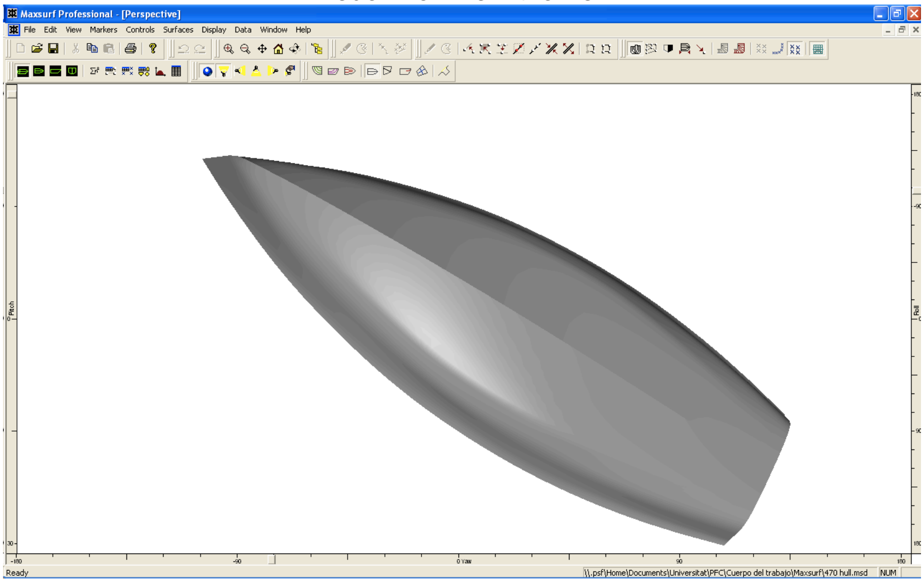
Appendix 4 Maxsurf Pictures



Maxsurf Modelling Interface



Model View from the Bow



Model View of the bottom

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